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# The life cycle and management of *Echinothrips americanus* (Thysanoptera: Thripidae)

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## ABSTRACT

The development times of *Echinothrips americanus* (Morgan) (Thysanoptera: Thripidae) on greenhouse peppers and cucumbers were determined, and commercially available predators of thrips were evaluated as potential biological controls for this pest. Development times on cucumber were 15.6 d ± 1.8, 3.6 d ± 0.8, 2.1 d ± 0.4, and 5.2 d ± 0.9 for egg, first-instar, second-instar and pupa, respectively. Development times on pepper were 15.0 d ± 2.1, 6.0 d ± 2.1, 5.5 d ± 1.2, and 5.2 d ± 1.0  for egg, first-instar, second-instar and pupa, respectively. Development from egg to adult took 26.5 d on cucumber and 31.7 d on pepper.  The development time for the pest on pepper is about 20% longer than on cucumber.  The predators, *Orius insidiosus* (Say) (Heteroptera: Anthocoridae), *Amblyseius cucumeris* (Oudemans) (Acarina: Phytoseiidae) and *Amblyseius degenerans* (Berlese) (Acarina: Phytoseiidae) were compared on *E. americanus*. *Orius insidiosus* significantly reduced thrips populations, but the two predator mite species did not.  Our results indicate that *O. insidiosus* has the most potential as a biocontrol agent.

**Key words**:  Life cycle, biological control, predators, British Columbia, greenhouse, pepper, cucumber, *Orius insidiosus*, *Amblyseius cucumeris*, *Amblyseius degenerans*.

## INTRODUCTION

The greenhouse vegetable industry in British Columbia relies heavily on the use of beneficial insects and mites for biological control of arthropod pests (British Columbia Ministry of Agriculture, Fisheries and Food 1996).  Control measures for new pests must be compatible with currently used biological control programs.   Development of compatible programs requires knowledge of the biology of any new pest.

*Echinothrips americanus* (Morgan) (Thysanoptera: Thripidae) has a reported distribution from southern Quebec to Florida and west to central Iowa (Stannard 1968). It is an important pest of poinsettias in the Eastern United States (Oetting 1987).

*Echinothrips americanus* was first found in a commercial greenhouse cucumber crop in the Fraser Valley in 1994.  Damage to plants was restricted to the foliage.  The fruits

were not affected. *Echinothrips americanus* reappeared on cucumber plants in the same greenhouse in March of 1995, and the infestation was controlled with chemical insecticides. In July 1995, *E. americanus* was found in two different bell pepper greenhouses. Feeding by thrips damaged the leaves extensively and was severe enough in some areas of the greenhouses to kill the plants. Pepper fruits were damaged by feeding and had to be culled. The predatory mites, *Amblyseius cucumeris* (Oudemans) and *Amblyseius degenerans* (Berlese) (Acarina: Phytoseiidae), and the minute pirate bug, *Orius insidiosus* (Say) (Heteroptera: Anthocoridae), were present and may have been feeding on the pest.

The objectives of this study were to determine the development times of *E. americanus* on peppers and cucumbers and to assess and compare *O. insidiosus, A. cucumeris* and *A. degenerans* as predators on *E. americanus*. Development times were assessed:

1) To predict how fast the *E. americanus* population increases over the growing season.
2) To predict when susceptible stages of the pest are present in order to release natural enemies.
3) To predict when susceptible stages can be accurately predicted for the purpose of pesticide treatment.

## MATERIALS AND METHODS

*Development*

We obtained thrips for this study from a colony reared on cucumbers at the British Columbia Ministry of Agriculture, Fisheries and Food (BCMAFF) greenhouse at Abbotsford. *Echinothrips americanus* has six developmental stages: egg, first-instar larva, second-instar larva, propupa, pupa, and adult. Identification of the stages was based on description of these stages by Stannard (1968), Vance (1974) and Oetting and Beshear (1993). Magnifying glasses (10x) were used to identify stages. In this study, we considered the propupae and pupae as a single stage, the pupae. Their short duration and the fact that development was only monitored every day or two made it impossible to distinguish the stages.

We studied development times on three cucumber and three pepper plants. The plants were 6 weeks old and were grown in an *E. americanus*-free greenhouse at the Pacific Agriculture Research Centre - Agassiz. Cucumber plants were pruned to three leaves, and pepper plants were pruned to four leaves. Eight adult *E. americanus* were placed on each leaf of each plant and removed after 24 h. Each plant was then placed in a separate 50 cm x 50 cm x 37.5 cm mesh screen cage. The leaves were examined every 1 to 2 days and the number of individuals in each stage recorded. Because of the large number of first instar thrips on each cucumber leaf, the development of first instars was monitored on only six of the nine leaves. Larval development was monitored on all 12 pepper leaves. First and second instar larvae and pupae remained on the original leaf. The mean temperature was 23°C during the 14-h photophase and 19°C during the 10 h scotophase and mean RH was 45% during the experiment. The temperatures used are similar to those in commercial pepper greenhouses.

*Assessment of natural enemies*

Twelve, 9-week-old pepper plants of identical size and number of leaves were used in this experiment. Each plant was inoculated with 20 adult *E. americanus*, then placed in a cage. After 2 weeks, 20 more adults were placed on each plant. This was done to create two overlapping generations. The plants were then randomly divided into four groups of

three plants each. One group of plants was used as the control and the other three groups were treated with either *O. insidiosus, A. cucumeris* or *A. degenerans*. The predators were introduced at rates of four *O. insidiosus* per plant, 100 *A. cucumeris* per plant or 20 *A. degenerans* per plant. The predators were left to interact with the thrips for one month. The temperature, photoperiod, and RH were the same as for the development study. At the end of the experiment, leaves were washed to determine the number of *E. americanus* on the plants (Gillespie 1989). Analysis of variance (ANOVA) was used to test the differences in the number of *E. americanus* and the means were separated using the Tukey test (pairwise comparison of the three predator treatments against the control).

## RESULTS AND DISCUSSION

Development times on cucumber were 15.6 d ± 1.8, 3.6 d ± 0.8, 2.1 d ± 0.4, and 5.2 d ± 0.9 (mean ± SD) for eggs, first-instars, second-instars and pupae respectively. Development times on pepper were 15.0 d ± 2.1, 6.0 d ± 2.1, 5.5 d ± 1.2, and 5.2 d ± 1.0 (mean ± SD) for eggs, first-instars, second-instars and pupae, respectively. Total development times from egg to adult were 26.5 d and 31.7 d on cucumber and pepper, respectively. On poinsettia, Oetting and Beshear (1993) found the total development time at 20°C was 33.9 d. Thrips took about 20% longer to develop on pepper than on cucumber. We therefore predict that populations of *E. americanus* will increase faster on cucumber than on pepper. However, the thrips used to determine development time originated from a colony maintained on cucumber. Insects and mites adapt to host plants on which they are reared, and this may affect their life history on other host plants (Fry 1989, Gillespie and Quiring 1994). Nonetheless, this is the first record of the development time of *E. americanus* on host plants other than poinsettia.

### Table 1.

Number of *Echinothrips americanus* found on pepper plants in the presence of different predators. Means followed by same letter not significantly different (Tukey test, $p > 0.05$)

| TREATMENT | REP 1 | REP 2 | REP 3 | MEAN |
|-----------|-------|-------|-------|------|
| No predator | 36 | 44 | 249 | 109.7 *a* |
| *Amblyseius cucumeris* | 93 | 18 | 15 | 42.0 *a* |
| *Amblyseius degenerans* | 37 | 23 | -- | 30.0 *a* |
| *Orius insidiosus* | 0 | 10 | 3 | 4.3 *b* |

Predators had significant effects on the number of *E. americanus* after 1 month (Table 1; $F=4.99$, df=3, $p = 0.037$), but only *O. insidiosus* reduced their populations significantly relative to the control (Table 1; $p < 0.05$). Neither mite species reduced *E. americanus* numbers significantly relative to the control, but the counts were highly variable, and further replication would have been appropriate. This was not possible because the *E. americanus* colonies had to be destroyed before the 1996 growing season to prevent the risk of contaminating commercial greenhouses. In the course of the experiment, plants were not damaged extensively. We note that *E. americanus* is considerably larger than *Frankliniella occidentalis*, the most common pest thrips in vegetable greenhouses in British Columbia. *Amblyseius cucumeris* cannot prey successfully on second-instars of *F.*

*occidentalis,* partly because the thrips defend themselves against attack (Riudavets 1995). It is possible that neither predatory mite can successfully attack the larger *E. americanus* for similar reasons. We observed *O. insidiosus* attacking all stages of *E. americanus*, but saw no predation by either mite species. Our results indicate that, of the predators presently being used for biological control of thrips in British Columbia, *O. insidiosus* would be the most appropriate to use in a biological control program for *E. americanus.*

## ACKNOWLEDGEMENT

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# Collection and selection of natural enemies of twospotted spider mites for biological control

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## ABSTRACT

Natural enemies of the twospotted spider mite, *Tetranychus urticae* (Koch) were surveyed (at three locations) in the lower Fraser Valley, British Columbia. Our objective was to identify predators that might be used for the biological control of spider mites in greenhouse tomato crops. Three to four pots of bean plants infested with spider mites were exposed each week at each of three locations from early April through to October, in both 1992 and 1993. Predators were collected from these trap plants, identified and tested as potential predators of spider mites. Twenty-two species were collected, more than half of them predatory Hemiptera. Two species, *Feltiella acarisuga* (Vallot) (Diptera: Cecidomyiidae), and *Stethorus punctum picipes* (Casey) (Coleoptera: Coccinellidae) were specialist predators of spider mites. *Feltiella acarisuga* was the most promising candidate for use in biological control of spider mites (on tomatoes) based on the frequency with which it occurred on trap plants, its cosmopolitan distribution, and its monophagous feeding habits.

**Key words:** biological control, British Columbia, greenhouse, tomato, *Tetranychus urticae*, *Feltiella acarisuga*, *Therodiplosis persicae*, predators.

## INTRODUCTION

Biological control of twospotted spider mites, *Tetranychus urticae* (Koch) (Acari: Tetranychidae), by the predatory mite *Phytoseiulus persimilis* (Dosse & Bravenboer) (Acari: Phytoseiidae) is common on cucumber and pepper crops in greenhouses in British Columbia (Costello *et al.* 1992) and elsewhere (Lenteren & Woets 1988). Twospotted spider mites are also pests of greenhouse-grown tomatoes, and biological control using *P. persimilis* has been described (Hussey & Scopes 1985). Outbreaks of twospotted spider mites are common on greenhouse grown tomato crops in B.C. but attempts at biological control with *P. persimilis* have generally failed. The increase of populations of *P. persimilis* on tomato crops is reduced by mortality of motile stages through entanglement on glandular hairs on stems and leaf petioles (Haren *et al* 1987), and by reduced life span and fecundity of adults due to contact with tomato leaves (Gillespie & Quiring 1994).

As one of many possible solutions to this problem, a different natural enemy could be used either to replace or to supplement *P. persimilis*. Importation of exotic predators should be done cautiously, however, and potential endemic natural enemies should be screened first. Consequently, the predators of spider mites were surveyed at three locations in the lower Fraser Valley, BC, using trap plants baited with spider mites. We report here the results of that survey, and of the initial screening process used to select candidate species for further study.
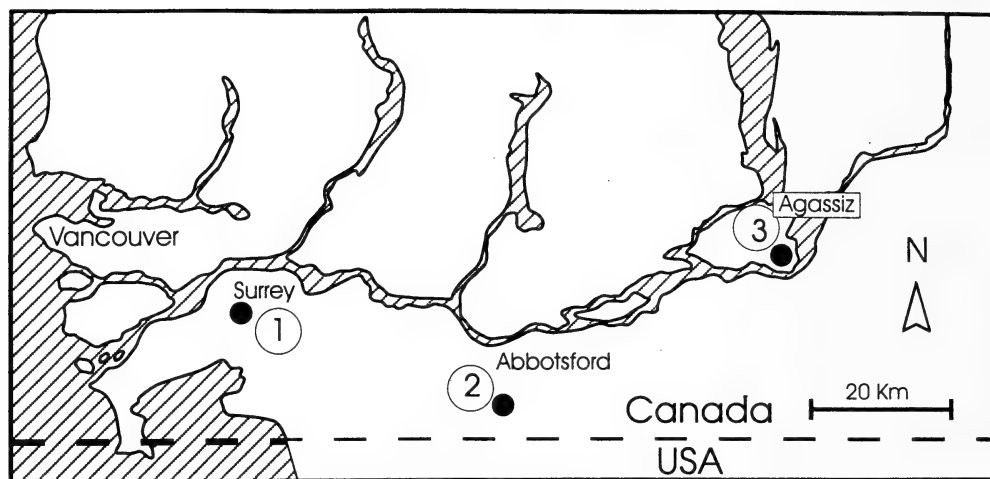
**Figure 1.** Map of the Lower Fraser Valley, B.C. Showing sample locations: 1. Green Timbers Nursery, Surrey, B.C.; 2. Agriculture and Agri-Food Canada Sub-Station, Abbotsford: 3. Agriculture and Agri-Food Canada Research Station, Agassiz.

## METHODS AND MATERIALS

Ten to twelve lima bean (*Phaseolus lunatus* L.) seeds were planted in compost mix in standard "8 inch" plastic pots, weekly from early April to late September of 1992 and 1993. After three to four weeks in a greenhouse at 22°C the primary leaves had completed growth, and the first secondary leaves were maturing. The plants were then lightly infested with approximately 200 adult and immature twospotted spider mites per pot, and taken to three different locations. At each location (Fig. 1) three to four pots were placed in 30 cm diam., plastic saucers, filled with water, under a 90 x 90 x 90 cm, plastic-roofed shelter with open sides. These plants were left unattended for one week.

After each week the trap plants were replaced with pots of fresh plants. The pots of exposed plants were carefully placed in plastic tote boxes with tight fitting, screened lids, and returned to the laboratory. Any obvious herbivores were removed, and known predators of spider mites were preserved and catalogued. Predators with unknown prey preferences and species whose role in the food chain was not obvious (eg. nymphs of some Hemiptera) were provided with spider mites on pieces of bean leaf for 24 h. Any insects that did not feed on spider mites were discarded. Species of unknown identity were reared to adults on a diet of spider mites and preserved for identification.

At site 1, in Surrey, trap plants were placed on mowed grass at the interface between a large open grass field, and a mature second-growth coniferous forest. At site 2, in Abbotsford, plants were in a mixed grass and clover fallow field. The site was surrounded by a windbreak of deciduous and coniferous trees, and much of the surrounding land was dedicated to raspberry culture. At site 3, in Agassiz, plants were among long grass at the interface between grass pasture and an extensive blackberry (*Rubus* spp.) thicket. The wild area behind the blackberry was mixed deciduous and coniferous forest.

# RESULTS AND DISCUSSION

More than 1500 specimens, representing 22 species of predator in seven orders and 14 families were collected from trap plants in 1992 and 1993 (Table 1). These species were either known predators of spider mites, or were observed to feed on them in the laboratory.

Most of the species (12 of 22) were Hemiptera and could be classed as generalist predators, feeding on spider mites and other small arthropods (see tables and citations in Chazeau 1985). With the exception of *Heterotoma meriopterum* (Scopoli) (Hemiptera: Miridae), all hemipterans were collected as adults. First instar nymphs of *H. meriopterum* were found on trap plants on several occasions. These were reared to adults on a diet of spider mites. It appears that adults of this species might lay eggs in or near to spider mite colonies.

Of the ten non-Hemipterous species, seven can be classed as generalist predators. Three species appeared to specialize as predators of spider mites. These were *Amblyseius sp.* (Acari: Phytoseiidae), *Feltiella acarisuga* (Vallot) (Diptera; Cecidomyiidae) and *Stethorus punctum-picipes* (Casey) (Coleoptera: Coccinellidae). Of these three, only *F. acarisuga* was collected at all three sites, and in virtually every month of the survey; it was the commonest predator. *Feltiella* spp. are predators of spider mites in many agricultural crops and are often considered the most important predators (Oatman *et al.* 1985, Pickett & Gilstrap 1986, Sharaf 1984). Moreover, *F. acarisuga* is virtually cosmopolitan (Gagne, 1995). In contrast, the other specialist feeder, *S. punctum picipes*, is restricted to western North America (Gordon 1985), and only 13 specimens were collected on 3 occasions.

Our objective was to select one or more natural enemies that might replace *P. persimilis* as a biological control for spider mites on greenhouse tomato crops. *Phytoseiulus persimilis* is ineffective on tomato plants, partly because motile stages are trapped on glandular hairs on stems and leaf petioles (Haren *et al.* 1987). Other phytoseiids and predators that walk between leaves to locate prey might also get trapped. Therefore trap plants were placed in water-filled saucers, in part to exclude such predators. This strategy was apparently successful, as only two species of predacious mites were found on trap plants. In a survey of spider mites on strawberry plants in the Fraser Valley, Raworth (1990) collected seven species of predacious Acari. All of the arthropod species found in this survey were collected either as winged adults, or as eggs, and first instars from eggs deposited by winged adults. The adults might therefore be able to avoid glandular hairs on stems and petioles when searching for prey.

The use of trap plants baited with target pest species and placed in areas where that pest is at a low density has been advocated as a way to select natural enemies for use in classical biological control (Pschorn-Walcher 1977). The natural enemies collected on such plants can presumably locate and feed on prey at low population densities. In this study, we placed trap plants baited with spider mites where spider mites were not obviously in outbreak, but might have been present naturally. At all sites, plants were placed in or near areas of mixed vegetation, separated from cultivated crops. Although spider mite density was not determined in surrounding vegetation, the lack of obvious damage on local plants presumably indicated low numbers. We therefore assumed that any natural enemies, particularly specialist natural enemies, that appeared on trap plants originated from nearby spider mite colonies that were not in outbreak or from distant outbreaks.

One of the desirable characteristics of natural enemies used for inundative biological control in greenhouses is their ability to locate hosts readily (Lentern & Woets 1988). Predators that discover spider mites on trap plants have either done so by chance or by some, presumably semiochemical, cues. It can be argued that those species that are known specialist predators of spider mites, and that also occur with regularity on trap plants probably have an efficient system for locating prey. In this context, *F. acarisuga* is an obvious candidate because of its consistently high numbers

**Table 1.**

Species of predatory insects collected on trap plants baited with twospotted spider mite, *Tetranychus urticae* (Koch).

| Species | Common Name | Type | Stage Collected[1] | # Collected[2] |
|---|---|---|---|---|
| **Acari**: Anystidae | | | | |
| *Anystis agilis* Banks | predatory mite | generalist | I, A | 54 |
| Phytoseiidae | | | | |
| *Amblyseius* sp. | predatory mite | generalist | I, A | 23 |
| **Hemiptera**: Miridae | plant bugs | | | 31 |
| *Heterotomma meriopterum* (Scopoli) | | generalist | I | |
| *Dicyphus* sp. | | generalist | A | |
| *Deraeocoris brevis* Knight | | generalist | A | |
| *Campyloneura virgula* (H.-S.) | | generalist | A | |
| Lygaeidae | big-eyed bugs | | | |
| *Geocoris* sp | | generalist | A | 1 |
| Anthocoridae | flower bugs | | | 35 |
| *Orius tristicolor* (White) | | generalist | A | |
| *Orius minutus* (L.) | | generalist | A | |
| *Anthocoris antevoleus* White | | generalist | A | |
| Berytidae | stilt-legged bugs | | | |
| *Neides muticus* (Say) | | generalist | A | 1 |
| Nabidae | damsel bugs | | | 33 |
| *Nabis alternatus* Parshley | | generalist | A | |
| *Nabis roseipennis* Reuter | | generalist | A | |
| *Nabis rufusculus* Reuter | | generalist | A | |
| **Diptera**: Cecidomyiidae | | | | |
| *Feltiella acarisuga* Vallot | predatory gall midge | specialist | E, I | 1224 |
| Syrphidae | | | | |
| *Scavaea pyrastri* (L.) | flower fly | "generalist" | I | 1 |
| **Thysanoptera**: Aeolothripidae | | | | |
| *Aeolothrips fasciatus* (L.) | thrips | generalist | A | 32 |
| **Neuroptera**: Chrysopidae | | | | |
| *Chrysopa* sp. | green lacewing | generalist | I | 40 |
| Hemerobiidae | | | | |
| *Wesmaelius* sp. | brown lacewing | generalist | E, I | 3 |
| **Dermaptera**: Forficulidae | | | | |
| *Forficula auricularia* (L.) | european earwig | generalist | A | |
| **Coleoptera**: Coccinellidae | | | | |
| *Stethorus punctum picipes*(Casey) | spider mite destroyer | specialist | E, I, A | 13 |
| *Coccinella* sp. | ladybird beetle | generalist | A | 1 |

[1] stage collected on plants.  E = egg, I = immature, A = adult
[2] total number collected at 3 sites during 2 years

A second important criterion for inundative biological control agents is that they should be able to complete their life history on the prey (Lentern & Woets 1988). Those predators found on infested baited trap plants as eggs and immatures probably meet this criterion. *Feltiella acarisuga*, *Wesmaelius sp.*, and *Stethorus punctum-picipes* all occurred as both eggs and immatures. In addition, we have seen *F. acarisuga* among spider mite colonies in greenhouses, apparently invading naturally. Our preliminary test release of *F. acarisuga* on tomato plants in a greenhouse became established and reproduced. On the basis of this evidence *F. acarisuga* was selected for further investigation as a potential candidate for inundative biological control of spider mites.

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# A thermal unit summation model for the phenology of *Rhagoletis completa* (Diptera: Tephritidae)

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## ABSTRACT

Predictions of various biological events in the life cycle of the walnut husk fly, *R. completa* Cresson in the Willamette Valley of Oregon were made using a thermal unit summation model. The model was based on data from a 3-year field study and was tested in 1993. The model was found to be more accurate than calendar dates at predicting several aspects of its phenology including adult emergence, female sexual maturity, and oviposition.

**Key words**: Insecta, Diptera, Tephritidae, walnut husk fly, *Rhagoletis completa*, thermal unit summation model, IPM, Oregon

## INTRODUCTION

Temperature-based models predicting pest phenology have become the basis of many agricultural pest management programs (e.g., AliNiazee 1976, 1979, Higley *et al*. 1986, Jones *et al*. 1989, 1991). These models have been widely used in many applications. For example, crop damage forecasting, studies of climatic limits to species distribution, population dynamics, the timing of insecticide applications and predicting pest development at different localities (AliNiazee 1976, Baker and Miller 1978).

The efficacy of chemical control of insects can be greatly influenced by the timing of spray applications. If timing is good, the control is optimized. Seasonal growth and development of insects in a geographical region can vary as much as 2 to 3 weeks from year to year, depending on climatic conditions, particularly temperature. With the walnut husk fly (WHF), *Rhagoletis completa* Cresson, variation in emergence could complicate pest control decisions, therefore, a temperature-based model of its phenology would be a useful tool in developing and implementing an IPM program for this insect.

Few data are available on the phenology of WHF (Kasana and AliNiazee 1996). The aim of the present study was to formulate and test a thermal unit summation model to predict phenological events of this key pest of walnuts in North America.

## MATERIALS AND METHODS

The study consisted of 2 parts: developing a thermal unit summation model, and subsequently testing it. The model was based on data gathered during 1990-92, using Pherocon AM aerial traps (Trece Inc., Salinas, California). Traps (4 in 1990 and 8 in 1991 & 1992) were placed 2 m above ground level in trees that were heavily infested in the previous season, and the numbers of trapped flies were recorded three times per week (Kasana and AliNiazee 1995). Captured flies were also sexed and placed in small plastic vials with alcohol and brought to the laboratory for dissection to determine sexual maturity of the females.

The data on oviposition, egg hatch, larval development and pupal formation were

derived from field observation over three years. One week after the first female was trapped, we sampled for the occurrence of oviposition. One-hundred nuts were collected randomly from all sides of trees and brought to the laboratory to check for infestation. Ten nuts, randomly selected, were dissected to determine egg hatch and larval development (Kasana and AliNiazee 1996).

Daily minimum and maximum temperatures were obtained from a weather station (OSU, Hyslop Farm) approximately 6 km from the study sites and at approximately the same elevation. Both air (107 cm above ground) and 5.08 cm soil temperatures were used.

The thermal units (day-degrees) were calculated using the method described by Baskerville and Emin (1969) employing a sine curve approximation from maximum and minimum temperature, with a lower threshold of $5°C$. No upper threshold was used because the daily maximum temperature rarely exceeded the upper developmental threshold of $34°C$ as determined in an earlier study (Kasana and AliNiazee 1994). The lower developmental threshold of $5°C$ was also used in earlier models (AliNiazee 1976, 1979) for *R. indifferens* and for *R. cerasi* (Boller 1966). Additionally, a detailed laboratory study of WHF (Kasana and AliNiazee 1994) established a lower developmental threshold of $5°C$ using the X-intercept method.

The model calculations of thermal units (TUs) were initiated on March 1. This date was chosen as it provided the least amount of variation (assessed by coefficient of variation) and has been used by earlier researchers for temperate-climate fruit flies (e.g., AliNiazee 1976, Reissig *et al.* 1979, Jones *et al.* 1989, 1991).

## RESULTS AND DISCUSSION

The TU requirements for emergence of different population levels based on aerial trap catches are given in Table 1. A thermal unit summation model was developed based on three year (1990-92) fly catch data in aerial traps (Table 1). The model, using air temperatures, predicts the emergence of WHF at accumulations of 1050, 1517, 1751, 1895 and 2198 TUs for first, 10%, 50%, 90% and 100% fly emergence levels, respectively. Different TU values were derived for soil temperatures. A comparison of reliability of calendar dates vs. model predictions as predictors of fly emergence at various percent population levels is also given in Table 1. Considering the variation in the fly catch dates, the data suggest that using TUs was a much more reliable method than using calendar dates to predict emergence, especially for 10% and 50% adult levels, while TUs were only slightly better than calendar dates in predicting the first emergence. Predictions using temperature above and below ground were almost equal compared with aerial traps, therefore, we recommend using a model based on air temperature data.

The TU requirements for various other biological events in the life cycle of WHF are given in Table 2. The TU summation method was more accurate than calendar dates for forecasting almost all biological events, especially for female sexual maturity and first oviposition. The first oviposition is a critical event for the IPM decision-making process because the first insecticide sprays should be applied at or before this event.

Although this study considered both air and ground temperatures, the use of soil temperature might be difficult. Very few farmers are likely to have access to soil temperatures needed for prediction. We therefore, suggest using aerial trap data and air temperature for practical applications.

As expected, different TU accumulations occurred at different dates in different study years. An analysis of the weather pattern suggests that the winter and spring of 1990 were normal, but they were colder in 1991 and warmer in 1992. This might explain the

**Table 1.**

Thermal unit (TU) requirements and comparison of estimates (Calendar vs. TU) of emergence of *R. completa* at various population emergence levels in the Willamette Valley, OR.

| Year | First | | DFMID | | 10% | | DFMID | | 50% | | DFMID | | 90% | | DFMID | | 100% | | DFMID | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date | TU | CD | TU | Date | TU | CD | TU | Date | TU | CD | TU | Date | TU | CD | TU | Date | TU | CD | TU |
| **Pherocon AM trap** | | | | | | | | | | | | | | | | | | | | |
| *Air temperature* | | | | | | | | | | | | | | | | | | | | |
| 1990 | 7/11 | 1066 | 2 | 1 | 8/10 | 1573 | 2 | 3 | 8/27 | 1807 | 3 | 4 | 9/05 | 1929 | 2 | 2 | 10/1 | 2262 | 6 | 10 |
| 1991 | 7/17 | 941 | 8 | 9 | 8/19 | 1450 | 11 | 4 | 9/04 | 1669 | 11 | 4 | 9/11 | 1762 | 8 | 11 | 10/9 | 2124 | 14 | 7 |
| 1992 | 7/01 | 1142 | 8 | 8 | 7/27 | 1527 | 12 | 0 | 8/12 | 1777 | 12 | 1 | 8/26 | 1994 | 8 | 6 | 9/11 | 2209 | 14 | 0 |
| *Soil temperature* | | | | | | | | | | | | | | | | | | | | |
| 1990 | 7/11 | 1583 | 2 | 0 | 8/10 | 2303 | 2 | 2 | 8/27 | 2636 | 3 | 3 | 9/05 | 2800 | 2 | 1 | 10/1 | 3240 | 6 | 6 |
| 1991 | 7/17 | 1458 | 8 | 7 | 8/19 | 2203 | 11 | 2 | 9/04 | 2500 | 11 | 4 | 9/11 | 2631 | 8 | 8 | 10/9 | 3108 | 14 | 5 |
| 1992 | 7/01 | 1693 | 8 | 6 | 7/27 | 2234 | 12 | 1 | 8/12 | 2590 | 12 | 1 | 8/26 | 2895 | 8 | 6 | 9/11 | 3191 | 14 | 1 |

Thermal units above 5° were accumulated from March 1. DFMID= Deviation from means in days, CD= Calendar date.

**Table 2.**

Thermal unit (TU) requirements and comparison of methods (calendar vs. TU) of estimating various biological events in the life cycle of *R. completa* in the Willamette Valley, OR.

| | | | First occurrence | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Mature female | | DFMID | | Oviposition | | DFMID | | Larva | | DFMID | | Larval exit | | DFMID | |
| | Date | TU | CD | TU | Date | TU | CD | TU | Date | TU | CD | TU | Date | TU | CD | TU |
| | Pherocon AM trap | | Air temperature | | | | | | | | | | | | | |
| 1990 | 7/23 | 1272 | 2 | 3 | 7/31 | 1393 | 0 | 0 | 8/10 | 1573 | 4 | 4 | 9/10 | 2006 | 6 | 5 |
| 1991 | 7/29 | 1124 | 8 | 6 | 8/08 | 1284 | 8 | 5 | 8/16 | 1401 | 10 | 7 | 9/13 | 1786 | 9 | 13 |
| 1992 | 7/13 | 1305 | 8 | 5 | 7/22 | 1457 | 9 | 6 | 7/27 | 1527 | 10 | 2 | 8/25 | 1978 | 10 | 3 |

Thermal units above 5° were accumulated from March 1. DFMID = Deviation from means in days, CD = Calendar date.

**Table 3.**

Model validation; a comparison of model predicted *vs.* actual dates of the beginning of various population levels/ biological events in the life cycle of *R. completa* under field conditions, Willamette Valley, OR, 1993.

| | | | | Flies captured/ biological events | | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | First | | Error (days) | 10% | | Error (days) | 50% | | Error (days) | 90% | | Error (days) | 100% | | Error (days) | Mature female[*] | | Error (days) | Oviposition[*] | | Error (days) |
| Events | Date | TU | ± | Date | TU | ± | Date | TU | ± | Date | TU | ± | Date | TU | ± | Date | TU | ± | Date | TU | ± |
| P | 7/9 | 1050 | - | 8/13 | 1517 | - | 8/31 | 1751 | - | 9/9 | 1895 | - | 10/6 | 2198 | - | 7/25 | 1233 | - | 8/3 | 1378 | - |
| A | 7/9 | 1043 | 0 | 8/04 | 1387 | 6 | 8/23 | 1657 | 5 | 9/3 | 1798 | 7 | 10/1 | 2132 | 5 | 7/23 | 1211 | 2 | 8/1 | 1324 | 3 |

P = predicted, A = actual, [*] = first occurrence

early emergence of the first fly in 1992 (June 29). In 1990, the emergence was 13 days later (July 11) than in 1992, and in 1991, the emergence was 19 days later (July 17).

Although the effect of pupal exposure to cold during the winter months was not analyzed in this paper, it has been suggested previously (Brown and AliNiazee 1977, AliNiazee 1988) that the duration of cold experienced by pupae may also affect TU requirements for development after diapause, and this could have a significant impact on the year-to-year variation of fly emergence in the field. Neilson (1962) reported that development of *R. pomonella* (Walsh) after diapause was rapid if the preceding cold period was 40 weeks or more. An effect of the length and intensity of cold period on phenology has also been reported for *R. indifferens* (Brown and AliNiazee 1977) and *R. cerasi* (Baker and Miller 1978). Smith and Jones (1991) investigated the effects of cold on *R. pomonella* emergence, and reported that pupae exposed to a longer cold period (79-191 days) required fewer TUs for emergence compared with those enduring shorter cold periods. AliNiazee (1988), in a detailed discussion of the subject, suggested that beyond a certain minimum (3-4 months) length of cold exposure had little effect either on the date of emergence or percentage of the emergence level of many *Rhagoletis* flies. In addition to temperature, other factors such as rainfall, amount of sunlight, soil type and host variety might also influence the adult emergence of *Rhagoletis* flies (Glass 1960, Dean and Chapman 1973, Neilson 1976).

The predictions of the models derived from aerial trap data and air temperature were tested during 1993 and were found more accurate than calendar dates. For example in 1993, the model predicted first adult emergence on July 9, female sexual maturity on July 25, and oviposition on August 3. The actual events in the field occurred on July 9, July 23 and August 1, respectively, (Table 3).

In summary, the TU summation model presented here predicts occurrence in the field of various biological events including fly emergence levels, dates of occurrence of mature females and first oviposition. These predictions are more accurate in the field than calendar dates and the model is therefore an improvement over the current practice which depends on calendar dates for applying insecticides. Similar programs have been successfully used with other *Rhagoletis* species including *R. indifferens* (AliNiazee 1976 & 1979, Jones *et al*. 1991), *R. cingulata* and *R. fausta* (Jubb and Cox 1974), and *R. pomonella* (e.g., Maxwell and Parsons 1969, Reissig *et al*. 1979, Jones *et al*. 1989).

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# Developmental threshold for the striped ambrosia beetle *Trypodendron lineatum*: a first estimate

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## ABSTRACT

We estimated the threshold temperature for development of *Trypodendron lineatum* (Oliv.). Western hemlock logs were inoculated with reproductively active beetles. Beetles developing inside them were reared in temperature controlled chambers at 18, 20, 25 and 30°C. Similar logs were set up outdoors. The outdoor, 25 and 30°C logs were replaced with field attacked logs when the inoculated beetles failed to establish. Sample disks were cut from each log every 6 days and dissected to find the number of all life stages. Beetles reared at 25 and 30°C developed more slowly than those outdoors or at 18 or 20°. Development rates in the 18 and 20°C chambers were used to calculate a threshold temperature of 13°C. We estimated that brood and parental beetles would emerge from the logs after accumulation of 265 degree-days above the 13°C threshold.

**Key words:** Ambrosia beetles, degree-day, development, forestry, inventory management, IPM, threshold temperature, *Trypodendron lineatum*.

## INTRODUCTION

The striped ambrosia beetle *Trypodendron. lineatum* (Oliv.) is a major pest for the forest industry of British Columbia. Attacks by this insect seriously reduce the value of high-grade sawlogs from coastal BC (Gray and Borden 1985; McLean 1992). Most of the major coastal softwood species are susceptible to attack including: Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco., western hemlock, *Tsuga heterophylla* (Raf.) Sarg., the true firs, *Abies spp.*, and Sitka spruce *Picea sitchensis* (Bong.) Carr. (Shore 1985). Logs are degraded when the valuable clear outer portion is damaged by brood galleries and stained by associated fungi introduced by attacking beetles (McLean 1985).

McLean (1992) reported that over 86% of infested logs were attacked while lying in the forest. The remaining 14% were attacked during transportation and storage. Populations of beetles from the forest are transported inside logs to dry land sorting areas, log boom storage areas and sawmills (Borden 1988). Infested logs here provide an "inoculum" of beetles and the surrounding forest margins are contaminated when "brood beetles" emerge from the logs in late summer and fly to overwintering sites in the adjoining forest floor. In the following spring, these beetles become the attacking mass flight that can infest any susceptible logs in the area. The brood beetles are sexually immature and pass the winter in reproductive diapause (Borden 1988). They do not respond to pheromones and cannot be trapped when they leave the logs in the late summer (Lindgren and Borden 1983). Pheromone traps therefore catch few flying brood

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beetles in late summer. To predict emergence from logs, a heat sum model would be most useful. Knowing the date of emergence, bundles of trap logs could be removed in time and high value log booms could be moved to low risk tie-ups away from forested shorelines.

McIntosh and McLean (1992) devised a life stage development index for *T. lineatum*. This model predicted the number of days ambrosia beetles needed to complete development and helped managers to determine where and when logs had been attacked. However, this index was based on local information and could not be used reliably over wider geographic areas. To be more broadly applicable, this index would have to account for the effect of temperature on *T. lineatum* development. A heat sum model would predict beetle emergence more reliably.

Our objective was to determine the threshold temperature for *T. lineatum* development experimentally so that the emergence of brood beetles could be predicted anywhere on the basis of accumulated degree-days. This would allow for improved integrated pest management of *T. lineatum* in dry land sorting and storage areas.

## MATERIALS AND METHODS

Four environmental chambers, three "Hotpack", and one Percival® I-30B were calibrated in 1993 and set to 18°C, 20°C, 25°C and 30°C. In a fifth treatment, three 3 m logs were laid lengthwise north-south 10 cm off the ground and completely exposed in the open at the UBC South Campus. Campbell Scientific CR10 dataloggers were programmed to measure temperature at 5 min intervals and to store an average every 30 min (McIntosh 1994) in each of the environmental chambers and outdoors.

*Host material.* Second growth western hemlock logs cut in November 1992 from the Cypress Bowl area near Vancouver, BC, were used first in this study. Logs were at least four months old (Dyer and Chapman 1965) and suitable for inoculation with *T. lineatum* in April 1993. The size of the chambers restricted the dimensions of the logs to a maximum top diameter of 30 cm and a maximum length of 75 cm. Each log was ringed with 1 cm masking tape at 5 cm intervals. Four logs fitted in each chamber. The cut ends of all logs were sealed with paraffin wax to reduce drying.

*Trapping.* Before the *T. lineatum* spring flight, 20 semiochemical-baited Lindgren® 12-unit multiple funnel traps were set 20 m apart in the forested margin to the north of the Point Grey log booms on the North Arm of the Fraser River in Vancouver[2] Ethanol (95%), released at a rate of 50-60 mg/24 h from a 20 ml polyvinylchloride (PVC) sheath suspended down the center of the funnel trap and one PVC "Flexlure" strip emitting the aggregation pheromone lineatin at a combined release rate of 50 µg/24 h was hung from the second funnel from the top and one from the second funnel from the bottom. This placement is recommended by Lindgren (1983). Insects collected from these traps in April were sexed and used to inoculate the logs.

*Inoculation.* A Fisher Scientific #2 (6 mm diam) cork-borer was used to cut 12 evenly spaced holes in the bark of each 5 cm section. One pair (male and female) of freshly trapped adults was placed in each hole and covered with a 2 cm square sheet of 1 mm mesh Fiberglass insect-screen fixed to the bark with four steel staples (Fig. 1). One set of logs was inoculated each day and stored at room temperature (approximately 16°C) for 24 h to allow the insects time to establish.

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[2] Lures purchased from Phero Tech Inc. 7572 Progress Way, Delta, B. C.  V4G 1E9

*Sampling.* Brood development was monitored by cutting a 5 cm disc from one end of one log in each of the four treatment chambers and the outdoor logs in a six-day sampling sequence (Fig. 2). Discs with less than 12 galleries were rejected. Each sampling day, all 12 galleries were dissected to determine the stages of beetle development in each treatment. All life stages present were identified and recorded as described by McIntosh and McLean (1992). After each disc was removed, the cut surface of the log was covered with plastic to reduce moisture loss. Brood mortality was assessed by comparing the number of fully developed niches where teneral adults had been with the total of egg, larval and pupal niches. Niches at least 3 mm long with their frass-sealed entrance broken were tallied as "fully developed".

Initial sampling and dissections revealed that inoculations were not successful in two of the chambers and in the outdoor logs. Some beetles bored through the Fiberglass stapled over the inoculation hole. Field attacked logs from Pemberton BC were used to replace these three sets of logs. Treatments were restarted on June 17, 1993 in the 30°C chamber and June 18 in the 18°C chamber and outdoor logs. Initial dissection of these wild-attacked logs revealed only parental adults and some galleries with eggs. The attack date was estimated as May 12-13, 1993, based on temperatures at Pemberton and the insect development index described by McIntosh and McLean (1992).
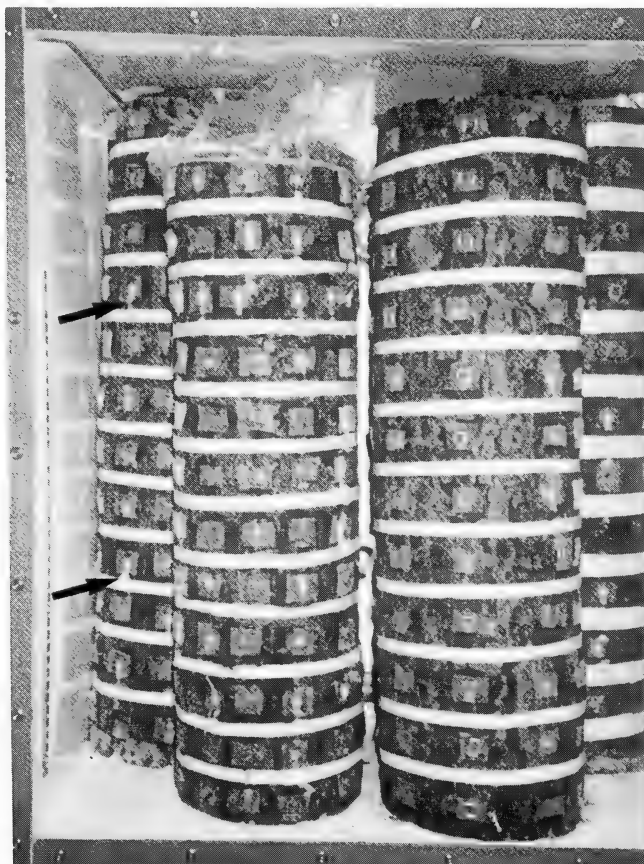


**Figure 1.** Logs with brood developing after inoculation with male and female *T. lineatum* pairs. Arrows indicate dust below the entrances of the inoculation holes. Staples show as a pale square over some of the holes
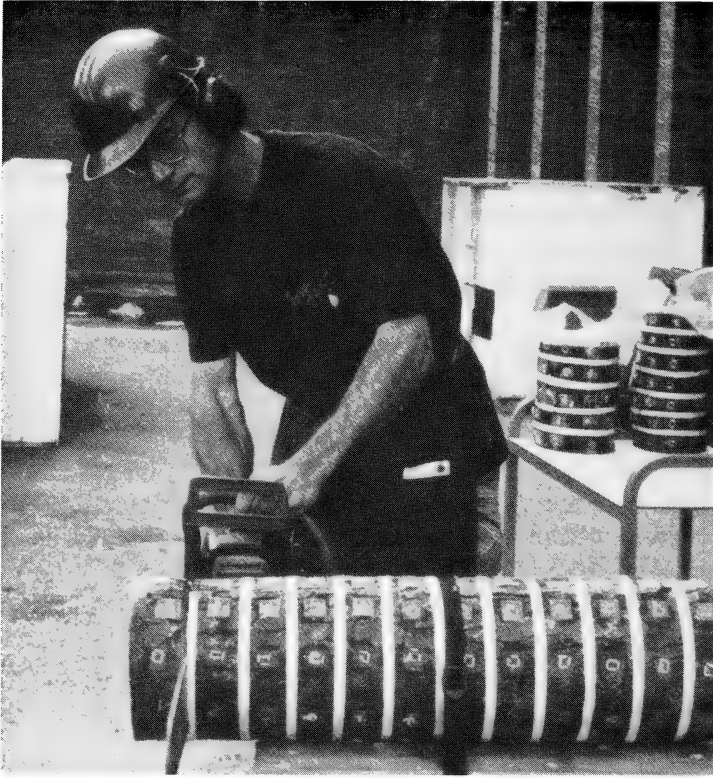
**Figure 2**. Disk being cut from a 75 cm log for dissection. Masking tape is used to guide the cut.

*Determination of Threshold Temperature ($T_o$)*.  Between May 1 and Aug 27, mean daily temperatures in all treatments were derived from the 30 minute averages recorded by the CR10 loggers. Values for the number of days exposure at different controlled temperatures ($T_e$) were calculated from the number of days needed for 50% of the eggs to develop into 50% of the total of teneral adults in the 18 and 20°C chambers.

The heat sum in degree-days, was calculated from Equation 1.

$$\text{Heat Sum} = \sum_{j=1}^{n} \text{Number of days at } T_e \text{ (}Mean\ Temp\text{ CR 10)} - T_o \qquad \text{Equation 1}$$

Where:  $T_e$ = *Number of days exposure in* 18° C *and* 20° C *Chambers*
   $T_o$ = *Threshold temperature*
   $j$ = *Symbol for days (1 to n)*

The threshold temperature ($T_o$) can be found algebraically using a simultaneous heat sum equation (Equation 2). Because development had already begun in all the wild attacked logs, the median development times were used to calculate the starting date as described by Welch *et al.* (1981). The percentage of each developmental stage was calculated using cumulative counts of each life stage at each temperature. An estimate of the time required for *T. lineatum* to develop from 50% of the eggs (Eggs$_{50}$) to 50% of the teneral adults (Teneral$_{50}$) was used with the Eggs$_{50}$ as the start point. The number of days needed at 20°C and 18°C were used and values inserted into the heat sum equation.

Number of Days at 20° C $[20.72 - T_o]$ = Number of Days at 18° C $[17.53 - T_o]$   Equation 2

Where:   *Mean temperature in 20° C Chamber = 20.72° C $\pm$ 0.17*
        *Mean temperature in 18° C Chamber = 17.53° C $\pm$ 0.60*
        *Number of Days at 20° C = 22.23 days (Teneral$_{50}$ - Eggs$_{50}$).*
        *Number of Days at 18° C = 38.82 days (Teneral$_{50}$ - Eggs$_{50}$).*

## RESULTS

*Dissections.* 818 galleries were dissected, 542 of these from logs in the environmental chambers, and 276 from logs outside. Mean temperatures recorded by the CR10 in each of the chambers are shown in Table 1.

**Table 1.**
Number of galleries dissected from logs in environmental chambers and outdoors May 13 - Aug. 22, 1993.

| Target Temp. | Mean CR10 Temp. (± SD) | No. Galleries Dissected | No. Niches[1] (Total) | No. Empty[2] Niches | Mortality (%) |
|---|---|---|---|---|---|
| 18[3] | 17.53 (± 0.60) | 216 | 802 | 576 | 28.2 |
| 20 | 20.72 (± 0.17) | 88 | 199 | 48 | 75.9 |
| 25 | 23.25 (± 1.08) | 122 | 243 | 231 | 4.9 |
| 30[3] | 28.22 (± 0.90) | 116 | 331 | 129 | 14.2 |
| Ambient[3] | 18.80 (± 1.88) | 276 | 1107 | 837 | 24.4 |

[1] All niches found in the dissections; egg, larval, pupal and teneral adult.
[2] Only fully developed teneral adult niches.
[3] Field infested logs.

*Calculation of Threshold Temperature ($T_O$).* The two lower controlled temperatures on the rising portion of the development curve were used to calculate the threshold. Both the number of degree-days above threshold temperature for each life stage and the number of degree-days from 50% eggs to 50% teneral adults was determined using the 18° and 20°C treatments (Table 2).

**Table 2.**
Time ($T_{50}$) required for 50% of each life stage to develop outdoors and in the 18 and 20°C chambers.

| Stage | Number of Days for 50% Development | | |
|---|---|---|---|
| | Ambient | 18 | 20 |
| Eggs | 33.16 | 38.03 | 13.27 |
| First instar larvae (L1) | 35.96 | 46.70 | 19.16 |
| Second instar larvae (L2) | 45.54 | 54.58 | 23.85 |
| Pupae | 54.58 | 71.04 | 24.09 |
| Teneral adults | 64.94 | 76.85 | 35.50 |

The threshold temperature ($T_O$) was determined from Equation 1. At 18°C the number of days for development (days$_{18°}$ ) from 50% eggs to 50% tenerals was 38.8 (76.8-38.0)

days. At 20° development took 22.2 (35.5 - 13.3) days (Table 2). These development times and the number of days for development under controlled 18°C and 20°C temperature conditions were inserted into the equations. The calculated threshold temperature ($T_O$) was 13.2°C. Because development rates at 18°C were closest to those outdoors, the development rate of in the 18°C treatment above the threshold of 13.2°C was used to demonstrate how the date of first beetle emergence can be predicted. Beetles should begin to emerge from the logs 265 degree days after the initial attack (Fig. 3).
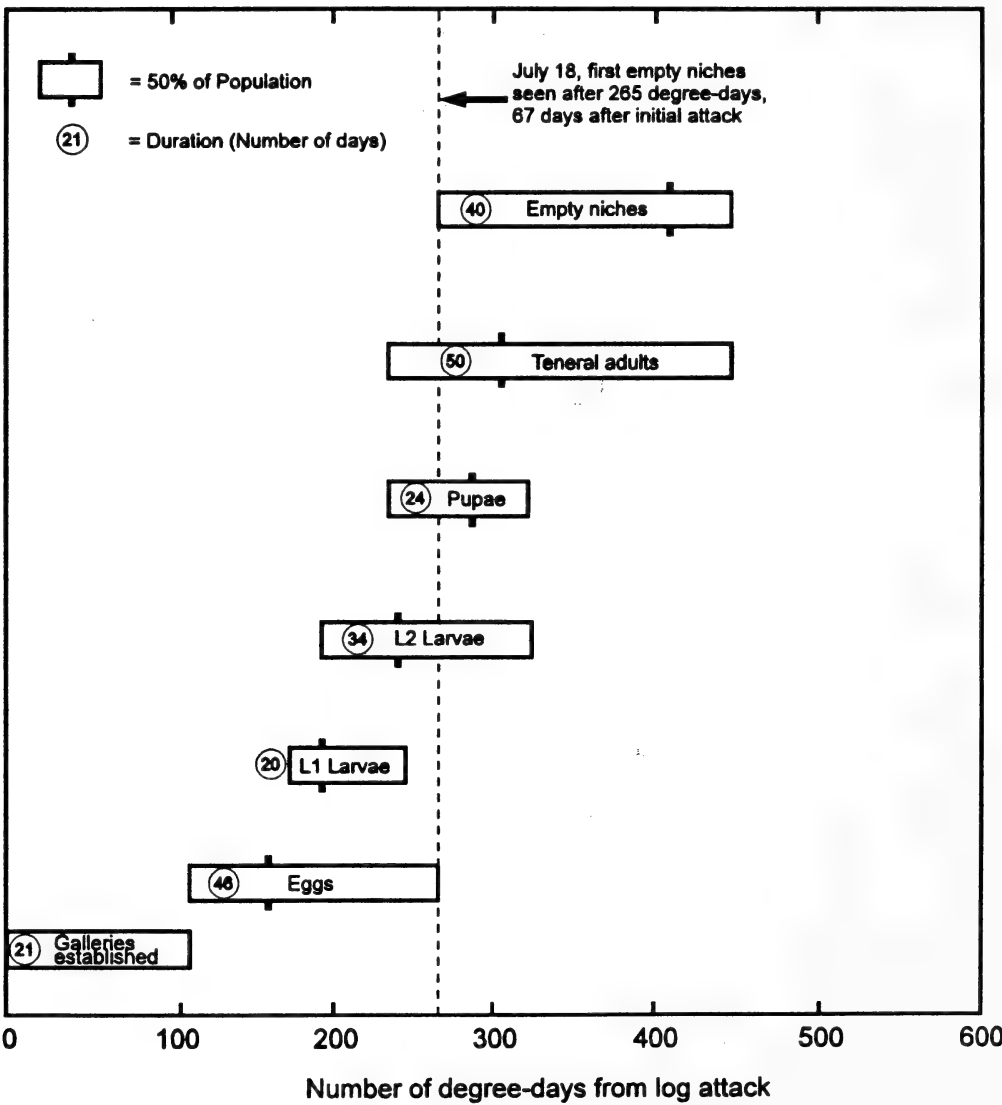


**Figure 3.** Chart showing the number of degree-days above 13.2°C for each *T. lineatum* life stage. Because eggs were already present in the logs from Pemberton, the 21 days of gallery development was estimated from the May 13 first attack flight.

# DISCUSSION

Measurements of insect development can be highly variable, particularly at lower and upper temperature extremes. As temperature increases from the lower limit to the optimum, the relationship between development rate and temperature is roughly linear. The widely adopted day-degree measure relies on this linearity (Gilbert and Raworth 1996) and is only valid between these temperatures (Wagner *et al.* 1984). In our study, as temperature increased from 18°C to 20°C, the development time decreased. Development time increased between 25 and 30°C and the optimum temperature was evidently exceeded. Because only two of the four controlled temperature treatments were below the optimum, we could not use regression analysis to determine the threshold temperature. Our study shows the importance of the very specialized relationship between *T. lineatum* and its host discussed by Borden (1988). The limited success of insect inoculation in these experiments could have resulted from either host or insect incompatibility. In the natural environment, beetles will not remain in an unsuitable host and flight trap catches in the spring indicate the presence of displaced beetles searching for suitable host materials. In retrospect, we should have used naturally attacked material instead of inoculating insects into host material of unknown suitability.

In addition, little is known about the bond between *T. lineatum* pairs, and research on the compatibility of mating beetles is lacking. Apparently, the males do not need to fly before they mate (Fockler and Borden 1972), and there is evidence that mating can occur in the forest floor before spring emergence (Chapman 1955). The abandonment of galleries seen in this study may indicate that there are other important mate selection criteria.

*Experimental design.* Experiments to confirm our preliminary estimate should use temperatures that span our calculated 13.2°C threshold. A range between 14 and 22°C would give a better estimate of the temperature threshold.

*Implications for management.* Each year, millions of dollars are lost to damage by *T. lineatum*. In spite of almost 50 years of research, logs are still attacked in the forest and infested logs brought into storage areas. A degree-day model to predict the flight of *T. lineatum* can be used throughout BC and will be a significant improvement over our local index (McIntosh and McLean 1992). The threshold temperature of 13.2°C derived in this study, enables beetle development to be described and brood beetle emergence to be predicted locally.

To predict the emergence of brood beetles, the activity of adults inside the log must be known. This study shows that brood beetles become active after 265 degree-days above threshold have accumulated. In 1993, a heat sum accumulation of 265 degree-days above 13.2°C corresponded with a calendar date of July 18 (Fig. 3). Brood activity and maturation feeding inside the log; as indicated by the presence of empty niches; can be used to indicate when the parental adults will leave the logs and thus will provide the cue for synchronizing late season trapping surveys to help focus mass trapping efforts the following spring (McIntosh and McLean 1997-In preparation).

Accurate timing of brood emergence from logs will provide the basis for more informed decisions for managing bundles of trap logs deployed to protect sorting and storage areas. For this tactic, the key to success is the timely removal and disposal of attacked trap logs. If they are not removed, the trap logs will contaminate the dry land sort and provide a breeding ground for ambrosia beetles. The cumulative heat sum for *T. lineatum* could be monitored at any dry land sort or industrial site, using local temperature measurements or Environment Canada temperatures from the nearest

airfield. With this information, the accumulation of degree-days can be monitored and the period of beetle emergence from the logs predicted.

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# Susceptibility of four bee species (Hymenoptera:Apoidea) to field weathered insecticide residues

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## ABSTRACT

Deltamethrin, methamidophos, methidathion, methyl parathion, permethrin, phosmet, pyridaben, thiocarb, and trichlorfon can all be applied in late evening with minimal hazard to bumble bees. Deltamethrin, formetanate, pyridaben and thiocarb can be applied in late evening with minimal hazard to honey bees. Deltamethrin, pyridaben and trichlorfon can be applied in late evening with minimal hazard to alkali bees. Deltamethrin, pyridaben and trichlorfon can be applied in late evening with minimal hazard to alfalfa leafcutter bees. In general the typical pattern of bee susceptibility to insecticide residues was the alfalfa leafcutter bee was more susceptible than alkali bee which was more susceptible than the honey bee which was more susceptible than the bumble bee.

**Key words**: Insecticides, honey bees, alfalfa leafcutter bees, alkali bees, bumble bees, toxicity

## INTRODUCTION

Bee poisoning from pesticides is a serious problem worldwide (Crane & Walker 1983, Johansen and Mayer, 1990, OEPP/EEPO 1992). However, there are few publications on comparative toxicology of insecticides to different species of bees using laboratory toxicology methods (Torchio, 1973; Tasei *et al.* 1987; Helson *et al.* 1993) and fewer still using the residue bioassay method (Johansen 1972, Johansen *et al.* 1983, Mayer *et al.* 1994).

Honey bees (*Apis mellifera* L.) produce honey and are valuable pollinators of many crops. Alfalfa leafcutter bees (*Megachile rotundata* (F.)) and alkali bees (*Nomia melanderi* Cockerell) are used to pollinate alfalfa seed. Bumble bees are good pollinators of many crops and since 1983 commercial colonies, including *Bombus occidentalis* Greene have been available (Free, 1993).

Organophosphates inhibit cholinesterase with consequent disruption of nervous activity caused by accumulation of acetylcholine at nerve endings. Carbamates are inhibitors of cholinesterase. Pyrethroids cause a rapid paralysis, consistent with their effects upon nerves (central or peripheral) or muscle.

This paper reports the effects of 14 different insecticides on honey bees, alfalfa leafcutter bees, alkali bees and bumble bees using our standard residue bioassay test.

## MATERIALS AND METHODS

Insecticides were applied to 0.004-hectare (40.5 $m^2$) plots of alfalfa with a R&D $CO_2$ pressurized sprayer (R&D Sprayers, Inc., 225D Hwy 104, Opelousas, LA 70570) in 234 liters of water mix/ha and the rates used are given in Table 1. The untreated check plots were sprayed with water. Tests of field-weathered insecticide residues were replicated four times with four foliage samples per treatment and time interval (Table 1). Samples consisting of about 500 $cm^2$ of foliage taken from the upper 15 cm parts of plants were placed in cages. Residual tests were conducted by caging 50 worker honey bees, 25 female leafcutter bees, 25 female alkali or 25 bumble bees with each of 4 foliage samples per treatment and time interval. The four bee species behaved similarly in the cages, crawling over the foliage to feed and on the sides of the cages. The

bees were maintained for 24-hour mortality counts in cages at 26 to 29° C, about 50% RH and fed 50% sucrose solution in a cotton wad (5 x 5 cm) placed on the cage bottom.

Cages were made from plastic petri dishes (15 cm diam.) with tops and bottoms separated by a cylindrical wire screen (6.7 meshes/cm) insert (45 cm long and 5 cm wide). The metal screen was stapled to form a circular insert which provided room in the cage for bees to fly.

Worker honey bees were taken from the top of colonies and anesthetized with $CO_2$ to facilitate handling. Leafcutter bee prepupae in leaf-piece cells were incubated at 30° C and 50% RH. Emerging adults were allowed to fly in the lab and collected off the windows. Alkali bees were gathered in a net from nesting sites and chilled to facilitate handling. Worker bumble bees (*B. occidentalis* southern strain) were obtained from the colonies (purchased from Bees West, Freedom, CA) in a dark room with a red light by removing bees and placing them in vials for later transfer to the cages. One hundred individuals of each species were weighed and the average weight per bee was 126, 31, 87, and 114 mg for honey bee workers, female alkali bees and female alfalfa leafcutter bees, and bumble bee workers respectively.

Abbott's (1925) formula was used to correct for the natural mortality. For each replicate, the number of dead individuals was recorded after 24 hours exposure. Data were analyzed using a two-step procedure. ANOVA was used to test for significant differences between means. The null hypothesis was rejected. Therefore we used Newman-Keuls studentized range test as a post hoc multiple comparison (Lund, 1989).

## RESULTS AND DISCUSSION

Pesticide toxicity varied across bee species and insecticides (Table 1). Deltamethrin was the least hazardous to all four bee species, while conversely oxamyl was uniformly highly hazardous to all bee species tested. The residual degradation time in hours (RT) required to bring bee mortality down to 25% was calculated from the residue bioassay data (Johansen *et al.*, 1983). Insecticides with an $RT_{25}$ of 2 h or less can be applied with minimal hazard to bees when they are not actively foraging. Insecticides reaching $RT_{25}$ within 2-8 h present a minimal problem to bees, if they are applied during late evening or night. Those with an $RT_{25}$ greater than 8 h are highly hazardous to bees and should not be applied or allowed to drift on blooming crops or weeds.

Deltamethrin, methamidophos, methidathion, methyl parathion, permethrin, phosmet, pyridaben, thiocarb, and trichlorfon with $RT_{25}$ less than 8 h can be applied in late evening with minimal hazard to *B. occidentalis*. Deltamethrin, formethanate, pyridaben and thiocarb with $RT_{25}$ less than 8 h can be applied in late evening with minimal hazard to honey bees. Deltamethrin, pyridaben and trichlorfon with $RT_{25}$ less than 8 h can be applied in late evening with minimal hazard to alkali bees. Deltamethrin, pyridaben and trichlorfon with $RT_{25}$ less than 8 h can be applied in late evening with minimal hazard to alfalfa leafcutter bees.

Johansen (1972) suggested the typical sequence of susceptibility of bees to insecticides is alfalfa leafcutter bee > alkali bee > honey bee > bumble bee and that this pattern was related to the size of the bee. However, in this test, bumble bees, although smaller than honey bees, were in general less susceptible to the insecticides. Of the 14 insecticides we tested, the leafcutter bee was less susceptible to none of the insecticides, alkali bees to one, honey bees to two and bumble bees to seven. Our results also showed that susceptibility followed the typical pattern although the ordering is tentative because many of the insecticides tested killed all the bees and differences could not be measures. Cypermethrin was less hazardous to alkali bees than to the other bees. Fenpropathrin and formethanate were less hazardous to honey bees than to the other bees.

**Table 1.**

Mortalities of bumble bees (BB), honey bees (HB), alkali bees (AB), and alfalfa leafcutter bees (LB) exposed to different age residues of insecticides applied to 0.004 hectare plots of alfalfa

| | | 24 hr % mortalities of bees caged with treated foliage | | | | | | | |
| | | BB | | HB | | AB | | LB | |
| TREATMENT[a] | Kg (AI)/h | 2 hr | 8 hr | 2 hr | 8 hr | 2 hr | 8 hr | 2 hr | 8 hr[b] |
| carbofuran 4F | | | | | | | | | |
| (Furadan) | 0.275 | 63a | 10a | 100b | 100b | 100b | 100b | 100b | 100b |
| cypermethrin 2.5E | | | | | | | | | |
| (Ammo) | 0.055 | 100a | 40b | 63b | 68a | 76ab | 29c | 83ab | 75a |
| deltamethrin 0.2E | | | | | | | | | |
| (Decis) | 0.209 | 3b | 0b | 10b | 4b | 15b | 17a | 27a | 19a |
| fenpropathrin 2.4EC | | | | | | | | | |
| (Danitol) | 0.22 | 95a | 94a | 52b | 29b | 100a | 100a | 100a | 100a |
| formetanate 92SP | | | | | | | | | |
| (Carzol) | 1.1 | 63b | 50a | 48a | 20b | 100c | 40a | 100c | 100c |
| methamidophos 4EC | | | | | | | | | |
| (Monitor) | 0.75 | 6b | 2b | 100a | 99a | 100a | 92a | 100a | 100a |
| methidathion 2E | | | | | | | | | |
| (Supracide) | 0.825 | 58b | 20b | 100a | 100a | 100a | 100a | 100a | 100a |
| methyl parathion 2F | | | | | | | | | |
| (Penncap-MS) | 0.55 | 73b | 6b | 100a | 100a | 100a | 100a | 100a | 100a |
| oxamyl 2L | | | | | | | | | |
| (Vydate) | 1.1 | 29b | 46b | 100a | 96a | 100a | 100a | 100a | 100a |
| permethrin 2E | | | | | | | | | |
| (Ambush) | 0.055 | 44c | 11c | 100a | 79a | 73b | 36b | 100a | 89a |
| pyridaben 75WP | | | | | | | | | |
| (Samite) | 0.44 | 0b | 10b | 23a | 31a | 36a | 15b | 48b | 6b |
| phosmet 50WP | | | | | | | | | |
| (Imidan) | 1.1 | 75b | 17b | 100a | 100a | 100a | 100a | 100a | 100a |
| thiocarb 3.2AF | | | | | | | | | |
| (Larvin) | 1.1 | 0b | 3c | 12b | 8c | 67a | 39b | 69a | 50a |
| trichlorfon 80SP | | | | | | | | | |
| (Dylox) | 1.1 | 7c | 0c | 73a | 85a | 76a | 6c | 45b | 25b |

[a] Means within a row of a chemical and for the same age residues followed by the same letter are not significantly different at the $p = 0.05$ level; Newman-Keuls studentized range test.
[b] Age of residues

The organophosphates seem more hazardous to honey bees than bumble bees (Table 2). It may be that bumble bees can detoxify thiophosphates faster or oxidize them to their toxic form more slowly than honey bees.

This work confirms and extends the work of Johansen *et al.* (1983) and Johansen and Mayer (1990) with three bee species and adds data on the hazard of insecticides to bumble bees. In general, bumble bees were the most tolerant to the insecticides. Our study clarifies which insecticides are safer for bumble bees, and adds to previous field weathered tests of Johansen (1972) and Mayer *et al.* (1994). Our study shows that the typical pattern of susceptibility of bees to insecticides has exceptions, so that each insecticide should really be tested on each bee species to determine the hazard.

**Table 2.**

Summary of effects of field weathered residues on alfalfa leafcutter bees (LB), alkali bees (AB), honey bees (HB) and bumble bees (BB).

| Common Name | Chemical Type | LB | AB | HB | BB |
|-------------|---------------|-----|-----|-----|-----|
| carbofuran | carbamate | | | | |
| cypermethrin | pyrethroid | | | | |
| deltamethrin | pyrethroid | + | + | + | |
| fenpropathrin | pyrethroid | | | | |
| formetanate | carbamate | | | + | |
| methamidophos | organophosphate | | | | + |
| methidathion | organophosphate | | | | + |
| methyl parathion | organophosphate | | | | + |
| oxamyl | carbamate | | | | |
| permethrin | pyrethroid | | | | + |
| pyridaben | pyridazinone | + | + | + | + |
| phosmet | organophosphate | | | | + |
| thiocarb | carbamate | | | + | + |
| trichlorfon | organophosphate | + | + | | + |

+ = not-hazardous

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# Mortality in eggs of pear psylla (Homoptera: Psyllidae) caused by fenoxycarb in combination with a water drench

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## ABSTRACT

Applications of the insect growth regulator fenoxycarb in pear before the appearance of foliage kills the eggs of pear psylla, *Cacopsylla pyricola* (Foerster), laid on newly expanded foliage 4 weeks after the application. We hypothesized that water in the form of rainfall or overhead irrigation transports the product from sprayed wood onto new foliage in sufficient amounts that eggs on foliage are killed. We tested this hypothesis by covering fenoxycarb-sprayed limbs with waterproof plastic, removing the covers 4 weeks later, immediately drenching half of the limbs with water, and then comparing egg hatch on drenched and non-drenched limbs. We also monitored egg hatch on uncovered limbs. Egg mortality 4 weeks after the application was two-fold higher on limbs drenched with water than on covered, non-drenched limbs (52% vs 26%). Mortality on limbs without fenoxycarb was less than 10%. Eggs deposited on fenoxycarb-treated but uncovered limbs also showed high rates of mortality (33-44%), which may have been due to rainfall in mid-April transporting fenoxycarb onto foliage.

**Key words:** pear psylla, insect growth regulators, Yakima Washington

## INTRODUCTION

The insect growth regulator fenoxycarb is effective against pear psylla, *Cacopsylla pyricola* (Foerster), an important pest of pears in the Pacific Northwest and parts of Europe (Solomon and Fitzgerald 1987, McMullen 1990, Higbee *et al.* 1995). Currently, it is being used against psylla (under the trade name 'Comply') during the prebloom period. Horton (1996) showed that an application of fenoxycarb at the delayed dormant stage in pear (bud scales just beginning to spread) reduced the hatch of eggs deposited on newly expanded foliage 4 weeks after the spray. Egg mortality was about 40% on sprayed trees compared to less than 5% on unsprayed trees (Horton 1996). Laboratory studies show that even highly dilute solutions of fenoxycarb cause extensive egg mortality in psylla (McMullen 1990), and one possible explanation for the egg-kill on unsprayed foliage is that fenoxycarb is transported from sprayed wood to foliage by rainfall or overhead irrigation. In this study, we looked at the effects of water on egg-kill by covering fenoxycarb-sprayed limbs with water-proof covers, and determining egg mortality on covered and uncovered foliage either with or without a water drench.

## MATERIALS AND METHODS

Experiments were conducted at an experimental orchard near Yakima, WA, in spring 1996 and 1997. Five treatments were compared: (1) control (no fenoxycarb, limb left uncovered); (2) fenoxycarb (limb left uncovered); (3) control (no fenoxycarb, limb covered); (4) fenoxycarb (limb covered); (5) fenoxycarb (limb covered, cover removed after 4 weeks and limb drenched with water). Fenoxycarb (0.15 g [AI] per liter of water) was applied with a handsprayer at the delayed

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dormant stage (19 Mar 1996; 21 Mar 1997). Control limbs were sprayed with water. In both years, 5 limbs per treatment (each at mid-canopy level) were randomly selected from approximately 20 trees. Treatments were then randomized among limbs. For the most part, limbs were on different trees; however, a few trees in both years had two limbs selected, in which case they were chosen from opposite sides of the tree. Each limb was 0.75-1.0 m in length. Limbs were sprayed just to the point of drip (50-100 ml of fenoxycarb or water per limb). For the uncovered controls (treatment (1)), 10 and 15 fruiting clusters were randomly selected from approximately 10 unsprayed trees in 1996 and 1997, respectively.

Treated and control limbs that were to be protected had an inverted, bowl-shaped cover (50 l in volume) constructed of 10 mil Mylar plastic. The cover was placed so that the limb was completely protected from precipitation. Holes were punched along the bottom edge of each cover, and twine was used to tie the bottom of the cover to the limb. Irrigation was delayed both years until after the study.

The water drench was applied by removing the cover 4 weeks after the spray (20 April 1996; 21 April 1997) and then drenching the limb with water using a handsprayer (water applied until runoff). Limbs were cut from the trees immediately after the drench and taken to the laboratory to monitor egg hatch. Limbs from the other 4 treatments were also collected at this time. Control samples were drenched with water before removing them from the trees.

To monitor egg hatch, 3-10 bloom clusters (depending upon egg densities) were taken from each limb. The clipped end of each cluster was put in water to keep the foliage turgid. Several egg-laden leaves on each cluster were marked with a small spot of typewriter correction fluid, and the eggs were counted. Clusters were then kept at 23° C to allow the eggs to hatch. After 8-10 days, unhatched eggs were counted. The 3-10 flower clusters from each limb were assumed to be a single sample, and the data were pooled from clusters on one limb. Therefore, sample sizes were 10 limbs for each treatment (5 limbs in 1996 + 5 limbs in 1997) except for the uncovered control, in which $n = 25$ (10 clusters in 1996 + 15 clusters in 1997).

Effects of treatment on the percentage of eggs failing to hatch were estimated with a two-way (year x treatment) analysis of variance (ANOVA). Percentages were arcsin transformed before analysis. Non-transformed means are given. Specific treatment comparisons were extracted with pre-planned single df contrasts.

## RESULTS

There were large differences among treatments in percentage of eggs failing to hatch in both years (Fig. 1). Patterns were similar between years, as indicated by nonsignificant year and year x treatment effects (Table 1). Egg mortality was very high in several of the fenoxycarb treatments, reaching 50% in the water drench treatment and 33-44% on limbs that were sprayed but left uncovered (Fig. 1). The increase in egg mortality caused by fenoxycarb was highly significant (Table 1; contrast (1)). Egg mortality was two-fold higher on fenoxycarb-sprayed branches that were drenched with water than on limbs that were covered but not drenched (Fig. 1; Table 1: contrast (2); mean [averaged over years] percentage kill = 52.9% [limb covered; drenched] and 26.3% [limb covered; no drench]). Contrast (3) tests whether egg mortality on fenoxycarb-treated limbs differed between uncovered limbs (i.e., those exposed to rainfall) and covered limbs in the absence of a water drench. There is a marginally significant indication (Table 1: contrast (3) [$p = 0.076$]) that egg mortality was higher on the uncovered limbs (mean [averaged over years] percentage egg kill = 38.7%) than on the non-drenched, covered limbs (mean percentage egg kill = 26.3%).
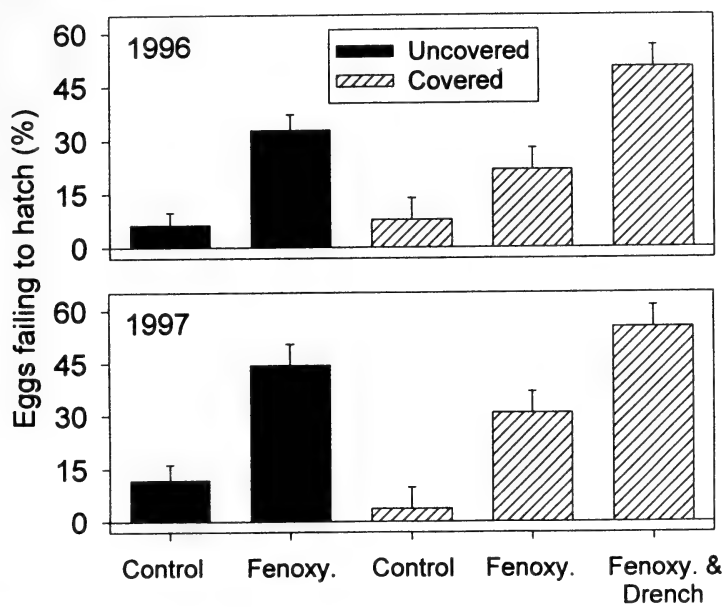
**Figure 1.** Mean (±SE) percentage egg mortality on control (no fenoxycarb) and fenoxycarb-treated limbs. Black bars: no plastic covers; cross-hatched bars: limbs with plastic covers. See Table 1 for results of ANOVA. $n = 5$ replicates per bar, except for uncovered controls in which $n = 10$ (1996) and 15 (1997).

**Table 1.**

Analysis of variance and contrasts summarizing the effects of fenoxycarb and water drench on hatch of eggs deposited by pear psylla (means summarized in Figure 1). Data arcsin transformed for analysis.

| Source | df | MS | F | $p > F$ |
|---|---|---|---|---|
| Year | 1 | 0.060 | 1.86 | 0.18 |
| Treatment | 4 | 0.807 | 25.23 | <0.001 |
| Year x Treatment | 4 | 0.017 | 0.52 | 0.72 |
| Error | 55 | 0.032 | | |
| **Contrasts:** | | | | |
| (1) Control versus fenoxycarb[1] | 1 | 2.69 | 84.06 | <0.001 |
| (2) Covered limb: fenoxycarb versus fenoxycarb + drench[2] | 1 | 0.43 | 13.34 | <0.001 |
| (3) Fenoxycarb: covered limb (no drench) versus uncovered limb[3] | 1 | 0.10 | 3.27 | 0.076 |

[1] Contrast compares the mean of the two control treatments (7.4% mortality) to the mean of the three fenoxycarb treatments (39.2%) (averaged over year).
[2] Contrast compares middle cross-hatched bar to cross-hatched bar on right (Figure 1; averaged over year).
[3] Contrast compares black bar on right to middle cross-hatched bar (Figure 1; averaged over year).

## DISCUSSION

By applying fenoxycarb at the delayed dormant stage and then again 4 weeks later, growers obtain good control of prebloom psylla populations (Hilton and Westigard 1994; Horton 1996).

However, the double application is very expensive, and many growers generally eliminate either the first or second spray; questions remain about the best timing for a single application (Hilton and Westigard 1994; Horton 1996). Horton (1996 and unpublished; see also Hilton and Westigard 1994) suggested that a single delayed dormant application, at least in certain years, provides a level of control similar to that of two applications. One factor contributing to the effectiveness of the delayed dormant spray must be the high rates of egg mortality that occur well into April (Fig. 1; and Horton 1996), despite the fact that these late-spring eggs are deposited almost exclusively on unsprayed foliage.

Rates of egg mortality were two-fold higher on covered, drenched limbs than on covered, non-drenched limbs (Fig. 1). The most logical explanation for this observation is that water transported fenoxycarb from sprayed wood onto unsprayed foliage; residue analysis would be necessary to confirm this explanation. There was a weak ($p = 0.076$) suggestion in the fenoxycarb treatments that egg mortality was higher on uncovered limbs than on non-drenched covered limbs (Table 1: contrast (3)), which may indicate that precipitation also transports the fenoxycarb. Overhead irrigation could not have been responsible for the egg mortality on the uncovered limbs, because the first irrigation in both years occurred after completion of the study. Both years had intervals of measurable rainfall between 10 April and the day that limbs were removed, including 0.36 cm of rain that fell the day before limb removal in 1997 (from National Climatic Data Center publications for city of Yakima).

Some of the egg mortality in the fenoxycarb treatments cannot be attributed to the action of water, because eggs that were deposited on covered limbs also showed increased levels of mortality even in the absence of a water drench (Fig. 1: compare middle cross-hatched bar to controls). Eggs laid on unsprayed surfaces by females that previously contacted fenoxycarb-treated surfaces have lower hatch rates (Higbee *et al.* 1995), and this might explain the 20-30% rates of egg mortality that occurred on the covered, non-drenched limbs.

In summary, our results reconfirm the observation that a single application of fenoxycarb before spread of bud scales causes mortality in eggs of pear psylla well into April (see Horton 1996). Results of the drenching experiment suggest that growers who rely on a single spray to manage psylla may improve control by judicious use of overhead irrigation. Furthermore, a single spray might prove to be less effective in a very dry spring than in a wetter spring, which may explain some of the variation among years in control that the senior author has noted.

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# Attraction of a bark beetle predator, *Thanasimus undatulus* (Coleoptera: Cleridae), to pheromones of the spruce beetle and two secondary bark beetles (Coleoptera: Scolytidae)

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## ABSTRACT

The bark beetle predator *Thanasimus undatulus* Say was captured in statistically significant numbers (total catch = 470, 713, and 137) in three field experiments using multiple-funnel traps baited with various combinations of pheromones for the spruce beetle, *Dendroctonus rufipennis* Kirby, and the secondary bark beetles *Dryocoetes affaber* Mannerheim, and *Ips tridens* Mannerheim. *Thanasimus undatulus* was attracted to frontalin and α-pinene, the commercial spruce beetle lure, alone or combined with the *D. affaber* pheromones (+)-*endo*- and (±)-*exo*-brevicomin. *Ips tridens* pheromones, (±)- and (+)-ipsdienol, significantly increased the numbers of *T. undatulus* attracted to spruce beetle lures. Additional *I. tridens* pheromone components, (-)-*cis*-verbenol and amitinol, did not increase attraction to spruce beetle lures with added (±)-ipsdienol. Attraction to *I. tridens* pheromones indicates that baiting susceptible hosts with *I. tridens* pheromones to induce competitive exclusion of the spruce beetle may also lead to increased densities of the natural enemy, *T. undatulus*.

**Key words**: *Thanasimus undatulus*, *Dendroctonus rufipennis*, *Ips tridens*, *Dryocoetes affaber*, ipsdienol, kairomone, predator, Princeton, British Columbia

## INTRODUCTION

There is an astonishing number of arthropod species associated with the subcortical galleries of bark beetles (Dahlsten 1982). Interactions among the co-existing organisms may greatly influence their dynamics and population distributions (Begon and Mortimer 1986). Mortality from arthropod predators and parasites may play an important role in keeping endemic bark beetle populations at low levels, thus minimizing the likelihood of large infestations (Whitmore 1983). Members of the family Cleridae are among the principal insect predators of several bark beetles (Dahlsten 1982).

The spruce beetle, *Dendroctonus rufipennis* Kirby, is the most destructive pest of mature spruce trees in Western North America (Safranyik 1988). Clerid predators may play only a small role in regulating spruce beetle populations. More significant causes of mortality include envelopment by resin, interspecific competition by other scolytids, and consumption by avian and dipteran predators (McCambridge and Knight 1972; Gara *et al.* 1995). *Ips tridens* Mannerheim and *Dryocoetes affaber* Mannerheim are the most common secondary bark beetles associated with the spruce beetle in Southern British

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Columbia. To develop semiochemical-based management tactics for the spruce beetle using competitive displacement or exclusion by the secondary species, the role of semiochemicals in interspecific communication between the spruce beetle, *I. tridens*, and *D. affaber* was investigated.

Entomophagous insects, including numerous species of clerids, commonly use scolytid pheromones as kairomones in host recognition (Bakke and Kvamme 1981, Billings and Cameron 1984). *Thanasimus undatulus* Say is a generalist predator that is attracted to ipsdienol (Miller and Borden 1990), *cis*-verbenol plus ipsenol (Miller *et al.* 1991), and frontalin (Ross and Daterman 1995).

*Thanasimus undatulus* is a predator of the spruce beetle. It was attracted to traps baited with frontalin as a spruce beetle lure (Kline *et al.* 1974), and aggregated in large numbers on frontalin-baited spruce trees (Dyer 1973). Dyer and Hall (1980) found that addition of seudenol to frontalin did not significantly enhance attraction of *T. undatulus*. There is evidence that it can recognize the enantiomers of pheromones of its prey. *Thanasimus undatulus* was attracted preferentially to *S*-(-)-frontalin in a Douglas-fir stand, while both enantiomers were equally attractive in a spruce stand, a finding consistent with the observation that the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, preferred *S*-(-)- or (+)-frontalin over the *R*-(+)- enantiomer, while the spruce beetle appeared to be equally attracted to both *S*-(-)-, *R*-(+)-, and racemic frontalin (Lindgren 1992). Such specificity in response suggests that the importance of *T. undatulus* as a predator of spruce beetles may have been underestimated. For example, its larvae may not be very effective as subcortical predators of spruce beetle larvae (McCambridge and Knight 1972; Whitmore 1983), but adults may prey largely unnoticed on adult spruce beetles when they are colonizing new hosts, a hypothesis that is consistent with Dyer's (1973) observations.

To maximize the efficacy of pheromone-based management of bark beetle pests, negative effects on natural enemies must be minimized and positive effects encouraged. Accordingly, in the course of other experiments (Poland and Borden 1997) we collected and counted the *T. undatulus* adults attracted to pheromone-baited traps. Herein we report the responses of this predaceous clerid to combinations of pheromones for the spruce beetle, *I. tridens* and *D. affaber*.

## MATERIALS AND METHODS

Field trapping experiments were conducted near Princeton, B.C. in mature stands composed of Engelmann spruce, *Picea engelmannii* Parry, lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann, and subalpine fir, *Abies lasiocarpa* (Hook) Nutt. All experiments utilized twelve-unit multiple-funnel traps (Lindgren, 1983) set out in randomized complete blocks with at least 15 m between traps.

Semiochemical attractants for the spruce beetle, *I. tridens*, and *D. affaber* are summarized in Table 1. Various combinations of pheromone components for the three species were tested to determine their roles in interspecific communication. Numerous *T. undatulus* were captured in three experiments. Experiment 1, conducted from 29 June to 11 August 1994, compared numbers of spruce beetle and *D. affaber* attracted to combinations of spruce beetle lures and racemic mixtures of the two components of the *D. affaber* pheromone, *exo*- and *endo*-brevicomin. It comprised 20 replicates of five treatments: 1) unbaited control; 2) spruce beetle lure; 3) spruce beetle lure with (+)-*exo*-brevicomin; 4) spruce beetle lure with (+)-*endo*-brevicomin; and 5) spruce beetle lure with (+)-*exo*-brevicomin and (+)-*endo*-brevicomin. Experiment 2, conducted from 14
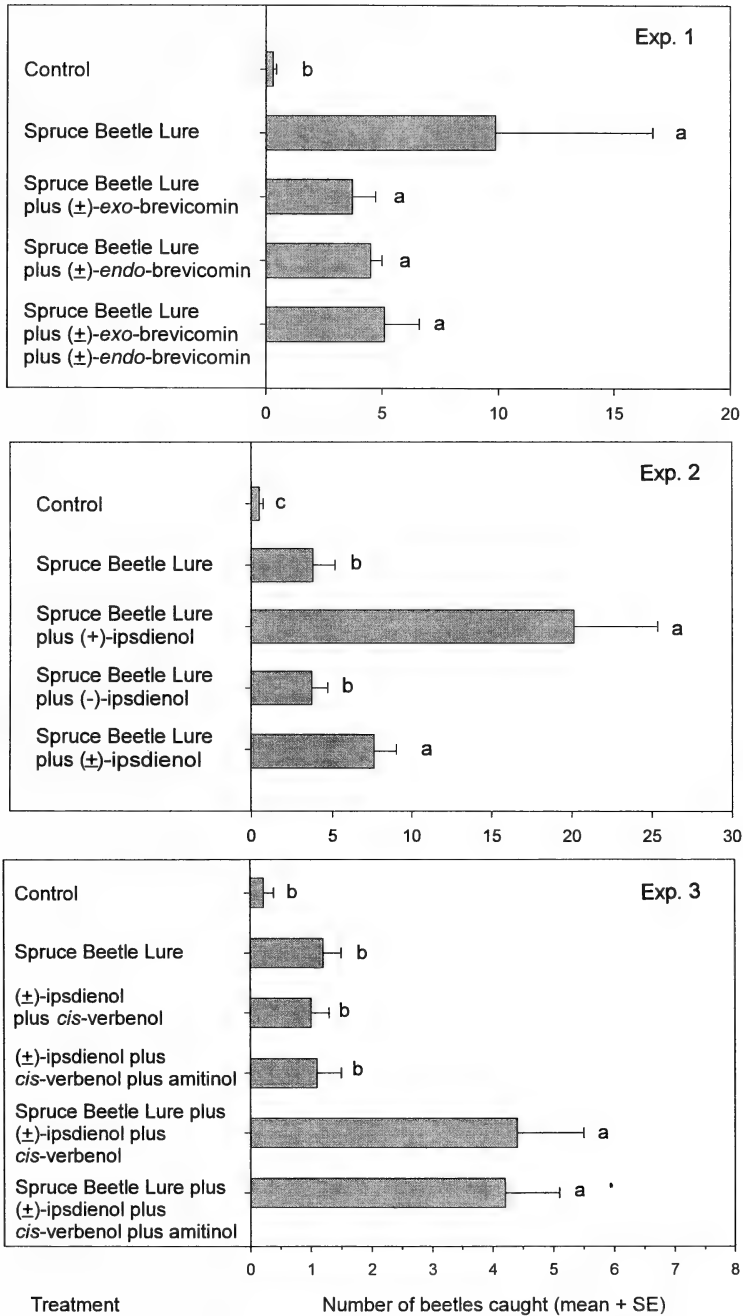
**Figure 1.** Mean number of *Thanasimus undatulus* captured in Experiments 1-3, 29 June - 17 Aug. and 14 July - 17 Aug. 1994, Arastra Creek, and 3 - 11 July 1996, Granite Creek, respectively, all near Princeton, BC. Spruce beetle lures consisted of frontalin released at 2.6 mg per 24 h and α-pinene released at 1.5 mg per 24 h. (±)-e*xo*- and (±)-*endo*-Brevicomin (Exp. 1) were released at 0.2 mg per 24 h. Enantiomers of ipsdienol (Exp. 2) were released at 0.2 mg per 24 h. In Experiment 3, ipsdienol, (-)-cis-verbenol, and amitinol were released from bubble caps at 0.2, 0.6, and 0.2 mg per 24 h, respectively. N=20, 20 and 10 for Experiments 1 - 3 respectively. For each experiment, bars with the same letter are not significantly different, REGW test, $p < 0.05$.

July to 17 August 1994, compared numbers of spruce beetle and *I. tridens* attracted to combinations of spruce beetle lures and the different enantiomers of ipsdienol, a component of the *I. tridens* pheromone. It comprised 20 replicates of five treatments: 1) unbaited control; 2) spruce beetle lure; 3) spruce beetle lure with (+)-ipsdienol; 4) spruce beetle lure with (-)-ipsdienol; and 5) spruce beetle lure with (±)-ipsdienol. Experiment 3, conducted from 3 to 11 July 1996, compared numbers of spruce beetle and *I. tridens* attracted to spruce beetle lures and three components of *I. tridens* pheromone, (±)-ipsdienol, (-)-*cis*-verbenol, and amitinol. It comprised 10 replicates of six treatments: 1) unbaited control; 2) spruce beetle lure; 3) (±)-ipsdienol and (-)-*cis*-verbenol; 4) (±)-ipsdienol, (-)-*cis*-verbenol, and amitinol; 5) spruce beetle lure with (±)-ipsdienol and (-)-*cis*-verbenol; and 5) spruce beetle lure with (±)-ipsdienol, (-)-*cis*-verbenol, and amitinol.

Spruce beetle lures consisted of α-pinene released at 1.5 mg per 24 h from 1.5 mL Eppendorf tubes and frontalin released at 2.6 mg per 24 h from 400μL Eppendorf tubes (Phero Tech Inc.). Racemic *exo*- and *endo*-brevicomin (98.0% and 95.6% chemical purity, respectively, Phero Tech Inc.) were released at 0.2 mg per 24 h from glass capillary tubes (1.0 mm ID) sealed at one end and placed in perforated Eppendorf tubes (Stock *et al.* 1990). Racemic and chirally pure (97%) ipsdienol were released at 0.2 mg per 24 h from bubble caps (Phero Tech Inc.). *cis*-Verbenol was released at 0.6 mg per 24 h from bubble caps (Phero Tech Inc.). Amitinol (*trans*-2-methyl-6-methylene-3,7-octadien-2-ol) was prepared by the method of Francke *et al.* (1980) from (±) ipsdienol (BRI, Danbury, Connecticut) and purified to 98% by flash chromatography on silica gel using pentane-ether (2:1, v/v) as eluent (H.D. Pierce, Jr., Dept. of Chemistry, S.F.U.). Amitinol was released from bubble caps at 0.02 mg per 24 h (Phero Tech, Inc.).

Captured *T. undatulus* were collected and stored in plastic bags at -18 °C until counted. The numbers captured were transformed by log (x + 1) to satisfy assumptions of normality and homoscedasticity (Zar 1984) and then subjected to ANOVA for randomized complete block design treating replicates as blocks. The means were compared by the Ryan-Einot-Gabriel-Welsch (REGW) multiple $F$-test (SAS 1990).

## RESULTS AND DISCUSSION

In Experiment 1, *T. undatulus* was attracted to spruce beetle lures alone and combined with (±)-*exo*-, (±)-*endo*-, or both (±)-*exo*- and (±)-*endo*-brevicomin (Figure 1). The brevicomins did not alter the number of *T. undatulus* attracted to the spruce beetle lure significantly. This indicates that *T. undatulus* either does not respond to (±)-*exo*- or (±)-*endo*-brevicomin or that responses to the brevicomins alone (not tested) are not enhanced by the presence of frontalin. Since clerids apparently exhibit preferences for enantiospecific pheromones (Lindgren 1992, Herms *et al.* 1991), a lack of response to (±)-*exo*- or (±)-*endo*-brevicomin by *T. undatulus* would not rule out kairomonal recognition of *D. affaber* as prey. For example, *T. undatulus* may require the enantiospecific pheromone of *D. affaber* consisting of a 1:2 ratio of the (+) enantiomers of *exo*- and *endo*-brevicomin (Camacho *et al.* 1994) to elicit a response. However, *T. undatulus* was not captured in sufficient numbers in experiments that tested spruce beetle and *D. affaber* responses to enantiospecific pheromone components for *D. affaber* to allow for statistical data analysis.

Spruce beetle lures also attracted *T. undatulus* in Experiment 2. (±)-Ipsdienol and particularly (+)-ipsdienol significantly enhanced the number of *T. undatulus* attracted to spruce beetle lures (Figure 1). Herms *et al.* (1991) found that the related species, *T. dubius* (F.), was attracted to different blends of (+)- and (-)-ipsdienol but preference

differed at different sites in Wisconsin and Michigan and in different years. Both frontalin and ipsdienol are known to attract *T. undatulus*. The results of Experiment 2 show that *T. undatulus* can recognize and respond to the (+) enantiomer of ipsdienol and that there is a synergistic effect of combining the two host kairomones. Because we have found that *I. tridens* produces mainly (-)-ipsdienol, *T. undatulus* may be better adapted to respond to pine engravers, *I. pini* (Say), that produce predominantly (+)-ipsdienol in B.C. (Miller *et al.* 1996). Alternatively, because *I. tridens* does produce small amounts of (+)-ipsdienol, *T. undatulus* may exploit a minor semiochemical product of *I. tridens* for prey location.

### Table 1

Summary of semiochemicals and their biological activities for *Dendroctonus rufipennis*, *Ips tridens*, and *Dryocoetes affabe*.

| Species | Semiochemical | Biological Activity | Reference |
|---|---|---|---|
| *D. rufipennis* | α-pinene | attractive | (Furniss *et al.* 1976) |
| | frontalin | attractive | (Gries *et al.* 1988) |
| *D. affaber* | (+)-*exo*-brevicomin (+)-*endo*-brevicomin | optimal attraction to 1:2 ratio of (+) enantiomers of *exo*-and *endo*-brevicomin | (Camacho *et al* 1994) |
| | (-)-*exo*-brevicomin (-)-*endo*-brevicomin | no activity inhibits response to optimal blend | |
| *I. tridens* | (±)-ipsdienol | attractive | (Moeck *et al.* 1985) |
| | (-)-*cis*-verbenol | attractive | (Poland 1997) |
| | amitinol | attractive | |

The results of Experiment 3 showed that traps baited with combinations of spruce beetle lures and (±)-ipsdienol and (-)-*cis*-verbenol or (±)-ipsdienol, (-)-*cis*-verbenol, and amitinol, caught significantly more *T. undatulus* than traps baited with spruce beetle lures alone, *I. tridens* pheromones alone, or the unbaited control traps (Figure 1). Although the addition of *cis*-verbenol or amitinol did not increase catches of *T. undatulus*, they did not decrease them significantly. *Thanasimus undatulus* may respond to key pheromone components that are commonly produced by many species, regardless of the presence of additional components that may be part of the pheromone blend of particular species.

The total numbers of *T. undatulus* captured across treatments were 470, 713, and 137 in Experiments 1-3 respectively. The corresponding numbers of scolytids captured were 435 spruce beetles, 2 *I. tridens*, and 2917 *D. affaber* in Experiment 1, 301 spruce beetles, 11 *I. tridens*, and no *D. affaber* in Experiment 2, and 73 spruce beetles, 1363 *I. tridens*, and 2 *D. affaber* in Experiment 3. *Thanasimus undatulus* outnumbered spruce beetles captured in all experiments and there were approximately 6 *D. affaber* captured for each *T. undatulus* in Experiment 1 and 10 *I. tridens* per *T. undatulus* in Experiment 3. These

results suggest that *T. undatulus* is attracted to pheromone components of its prey in numbers that may have an impact on scolytid populations.

Attraction of *T. undatulus* to *I. tridens* pheromones indicates that baiting susceptible host trees with *I. tridens* pheromones to induce competitive exclusion of the spruce beetle may also increase the density of the natural enemy, *T. undatulus*. If *T. undatulus* were to prey preferentially on the spruce beetle, the reduction of spruce beetle populations due to competitive displacement or exclusion by *I. tridens* (Poland 1997) would be augmented. On the other hand, the preferences of *T. undatulus* for small scolytids like *I. tridens* (Kline and Rudinsky 1964; Schmitz 1978) may partially offset the effects of competition on the spruce beetle. Non-preference by *T. undatulus* may simply reduce the level of interspecific competition by reducing population densities of both scolytid species.

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# Development of *Aphelinus asychis* (Hymenoptera: Aphelinidae) and its susceptibility to insecticides applied to mummies of its host, the green peach aphid

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## ABSTRACT

We examined the suitability of the green peach aphid, *Myzus persicae* (Sulzer), as a host for *Aphelinus asychis* Walker. The solitary parasitoid, *A. asychis* imported from France, has adapted to *M. persicae* reared on potatoes in the laboratory. Females deposited about 95 eggs over 21 d in various stages of the aphid including alates. The mean emergence was 83.3%, and the highest 92.3%. The longevity of female adult parasitoids was about 20 d. Total larval developmental time (14.5 d) was shorter than the adult longevity of females. Parasitoid larvae inside *M. persicae* mummies were less susceptible to the selective aphicide pirimicarb than to the broad spectrum chemicals, methamidophos and disulfoton. The mean daily emergence (6.1%) and cumulative emergence (73.3%) from mummies treated by pirimicarb were significantly higher than those from mummies treated by methamidophos (4.1 and 49.2%) and disulfoton (0.6 and 6.7%). The high fecundity and emergence, and reduced susceptibility of *A. asychis* to the pirimicarb show its potential as a biological control agent in integrated pest management programs for green peach aphid.

**Key words:** *Aphelinus asychis*, *Myzus persicae*, host suitability, chemical susceptibility

## INTRODUCTION

The green peach aphid, *Myzus persicae* (Sulzer) (Homoptera: Aphididae), is one of the most potentially harmful insects in the world (Tamaki 1981) because it has become resistant to many insecticides (Wyatt 1966, Rabasse and Wyatt 1985) and is a major vector of plant diseases such as potato leaf roll virus (van Emden *et al.* 1969). Thus, the need to develop integrated control approaches is very apparent.

Biological control is central to integrated pest management (IPM) programs where the use of chemicals is minimized, or selective insecticides are preferred (Hoy 1993). It is critical in biological control to maximize the utilization of native predators in combination with potential exotic natural enemies (Flint and van den Bosch 1981), yet no specific effort has been made to introduce exotic species to control green peach aphid on field crops, nor has using biological control agents on noncrop or alternative crop plants been adequately exploited (Biever 1995). *Aphelinus asychis* Walker (Hymenoptera: Aphelinidae) was first introduced to the United States in 1955 in order to control the spotted alfalfa aphid, *Therioaphis trifolii* Monell (Clausen 1956). The Aphelinidae are solitary endophagous parasitoids primarily of aphids in the family Aphididae (Stary 1988). Adult *Aphelinus* are very small (1 mm long) and thickset; the wings are short with reduced venation, and the antennae are elbowed. Mummified aphids are black, retaining the original size and shape of the aphid, and the dorsal exit hole is ragged. Otherwise

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these parasitoids resemble the Aphidiidae in biological details such as development time and fecundity although adults live somewhat longer (Rabasse and Wyatt 1985). *Aphelinus asychis* was studied as a biological control agent against pea aphid, corn leaf aphid, yellow sugar cane aphid as well as greenbug, *Toxoptera graminum* (Rondani), (Esmaili and Wilde 1972, Raney *et al.* 1973, Cate *et al.* 1977, Bai and Mackauer 1991). Hartley (1922) noted that *A. semiflavus* Howard fed on *M. persicae*, and later Ferrière (1965) synonymized *A. semiflavus* with *A. asychis*. However, Mackauer (1968) and Raney *et al.* (1971) left the European *A. asychis* as a separate species because of differences in their host pattern and a possible differing geographic strain. Gordh (1979) also classified *A. asychis* as a different species. In this study we follow Mackauer's classification because our *A. asychis* were originally imported from France to the Northwest Biocontrol Insectary and Quarantine at Washington State University, Pullman, WA, as potential biological control agents for Russian wheat aphid, *Diuraphis noxia* (Mordvilko) (Homoptera: Aphididae).

We conducted tests to assess the potential of *A. asychis* as a biocontrol agent for the green peach aphid on Solanaceae in a closed system. In the present study, laboratory experiments evaluated the suitability of *M. persicae* as a host for *A. asychis* in terms of parasitism, the developmental time of the parasitoid larvae, longevity of the adult female *A. asychis* and percent emergence rate. In addition, susceptibility of the parasitoid larvae inside *M. persicae* mummies to various insecticides were studied.

## MATERIALS AND METHODS

**Rearing.** A colony of holocyclic (alternating sexual and parthenogenetic generations) 'Yakima' strain *M. persicae* (from USDA-ARS, Fruit and Vegetable Research Laboratory in Yakima, WA) was maintained in Pullman, WA on radish, *Raphanus sativus* L., seedlings in 4 l glass jars. The opening of each jar was covered with nylon organdy to allow air circulation. Potatoes, cv. 'Russet Burbank', were planted in 3 l plastic pots and placed in an aluminum cage (30 x 30 x 45 cm). The cage sides were nylon organdy, and a sleeve provided access. The bottom of the cage was a metal plate. The top of the cage was covered with clear plastic for observation and for light to reach the plants. *Myzus persicae* were introduced when the plants were 30 cm high. Parasitoids were reared in the cages at 21 ± 1°C, ~45% RH, and constant light. A small amount of 15% honey solution was smeared on a piece of yellow paper (Post-it™) and placed in the upper portion of the cages to provide a supplemental carbohydrate source.

**Parasitism and developmental time.** Six cages were used to examine developmental time of *A. asychis* from oviposition to mummification. Each cage contained one potato plant infested with about 200 *M. persicae* in various stages that provided food and were oviposition hosts for *A. asychis*. The top of the soil in the pots and the bottom of the cage were covered by white sand to make the mummies more visible. An unmated pair of *A. asychis* newly emerged (< 1 d old) from *M. persicae* mummies on potatoes was released into each cage. Survival of *A. asychis* was checked daily and their activities observed and noted. An aspirator was used to transfer pairs of parasitoids to new cages every 24 hours. Time from oviposition to mummification and the number of mummies per cage were recorded. A camel-hair brush was used to move the blackened mummies to Petri dishes, where the duration of the mummy stage and adult emergence was recorded. A total of 12 pairs of adults and 121 offspring were observed.

**Chemical susceptibility.** Three insecticides commonly or experimentally applied to potatoes in Washington were used to treat black mummies (parasitized as 4th instar) on potato leaves by means of a hand-held sprayer. The applied insecticides were disulfoton (Di-syston®8, Miles Inc., Kansas City, MO), methamidophos (Monitor®4, Miles Inc.),

and pirimicarb (Pirimor®50DF, Zeneca Agro Co., Wilmington, DE) at the rates of 3.36, 0.84, and 0.28 mg a.i. per 100 cm$^2$, respectively. Water was applied to mummies for the untreated control. Each treatment was tested on 120 *M. persicae*, with 10 mummies (7 - 8 d old after complete mummification) from each of 12 *A. asychis* pairs. After the spray dried, 10 mummies on potato leaves were placed on filter paper in each Petri dish at 21 ± 1°C, ~45% RH, and constant light. Every 24 h the number of newly emerged adults of *A. asychis* was recorded. Cumulative and average daily emergence rates from different insecticide treatments were analyzed using analysis of variance and Duncan's multiple range test to detect significant differences (PROC GLM; SAS Institute 1989).

## RESULTS AND DISCUSSION

**Parasitism and development time.** Although we did not count the remains of aphids that had been killed by parasitoid feeding, we observed that during early adulthood, female *A. asychis* killed more aphids by feeding than by ovipositing eggs, and thus their oviposition rate was very low during this period (Fig. 1A). This is a critical period for *A. asychis* to obtain nutrition for the initiation of oogenesis, as well as for improved survival (Stary 1988). Females parasitized an average of 95 *M. persicae* (Fig. 1A), which is similar to that on greenbugs as recorded by Jackson and Eikenbary (1971). However, this is fewer than the 179 mummies/female produced on greenbugs in another study (Cate *et al.* 1973). The most mummies were observed on day 12 when a mean of 25.5 mummies/female were formed (Fig. 1B). This number is higher than the 16 mummies/female produced on greenbugs (Cate *et al.* 1973). The actual number of *M. persicae* killed by the *A. asychis* pairs must be more than the number of mummies produced by a female because both male and female *A. asychis* feed on aphids over their life span.

Adult females lived about 20 d (Table 1), which is within the range (14 - 26 d) reported for *A. asychis* females reported earlier (Zohdy and Zohdy 1976). However, the times required for mummification (3.5 d), and for emergence (11 d) were shorter than those (8 - 9.2 and 14.6 - 15.7 d, respectively) reported by Zohdy and Zohdy (1976). Compared with results of the study of *A. asychis* on greenbugs (Cate *et al.* 1977), the period of mummification is shorter but the time for emergence is longer. Different aphid hosts may affect the development time of the parasitoid. The development of the immature stages of *A. asychis* in mummified aphids may also be affected by the nutritional composition of host plants (Zohdy and Zohdy 1976). In addition, the age of aphids affects the percent of parasitoids emerging (Cate *et al.* 1977). Since the *M. persicae* used in this study were of various ages, the mean percent emergence, 83.8%, was slightly lower than those (85 - 95%) from greenbug mummies in the study by Cate *et al.* (1977). However, it was higher than those from corn leaf aphid (65 - 76%), greenbug (59 - 82%), and yellow sugarcane aphid (57 - 80%) mummies found by Raney *et al.* (1971). *A. asychis* can continue to reduce *M. persicae* populations locally because overall developmental time from oviposition to emergence (14.5 d) is shorter than the longevity (19.9 d) of the female adult. A mean emergence rate as high as 92.3% demonstrates the suitability of *M. persicae* on potato as hosts for *A. asychis*.

**Susceptibility to chemical insecticides.** The mean daily emergence rates of *A. asychis* from *M. persicae* mummies treated by various insecticides were significantly different ($F = 32.15$; df = 3, 44; $p < 0.001$) (Table 2). There was no significant difference in emergence between untreated control (6.8 %) and pirimicarb treatment (6.1%). However, the mean daily emergence of *A. asychis* from mummies treated with pirimicarb was significantly higher than from mummies treated with either methamidophos (4.1%) or disulfoton (0.6%), whose emergence rates were also significantly different from each
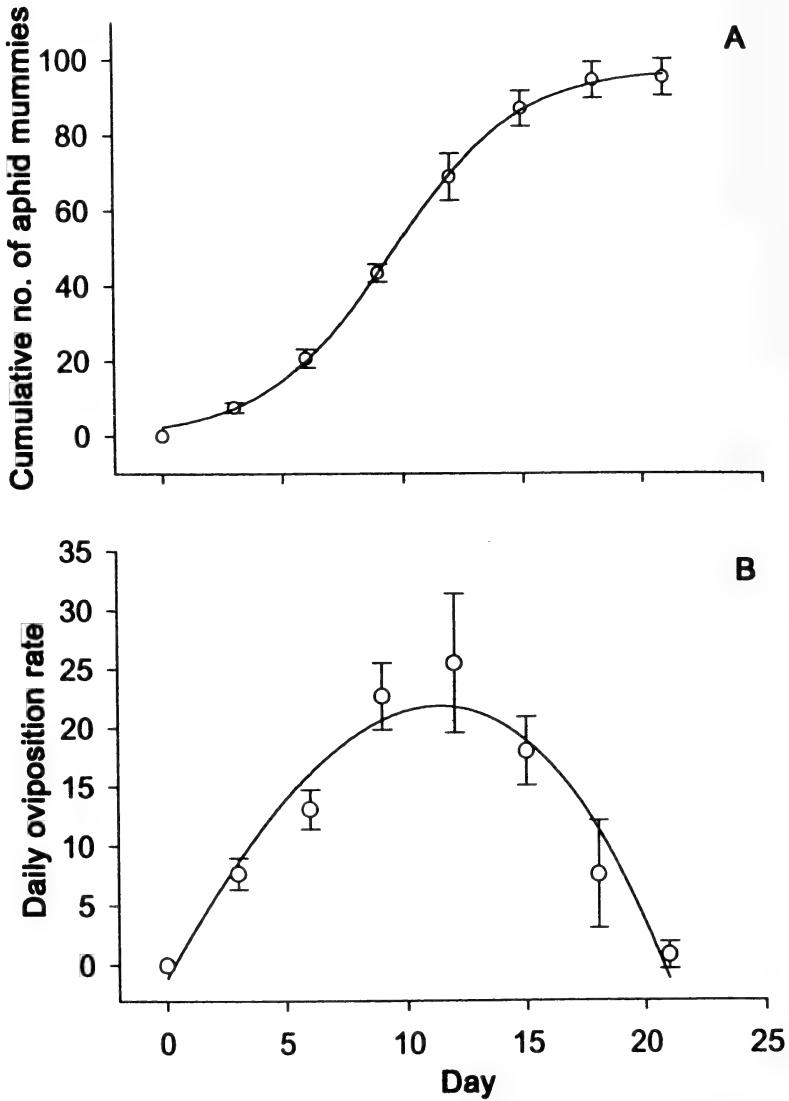
**Figure 1.** Cumulative numbers of aphid mummies (A) and daily oviposition rate by a pair of *Aphelinus asychis* (B). Solid lines in A and B represent nonlinear curve fits, $p<0.05$.

**Table 1.**
Longevity of adult females, time required for mummification and emergence, and percent emergence of *A. asychis* at $21 \pm 1°C$, 45% RH and continuous light. 12 females were used to determine longevity and 121 parasitoid offspring were used to determine development and emergence.

| | Development time (d) | | % emergence | Longevity of female (d) |
|---|---|---|---|---|
| | From oviposition to mummification | From mummification to emergence | | |
| Mean ± SD | 3.5 ± 0.5 | 11.0 ± 0.6 | 83.8 ± 6.3 | 19. 9 ± 1.1 |
| Range | 3 - 4 | 10 - 13 | 71.4 - 92.3 | 18 - 21 |

other. Cumulative emergence rates from the different insecticide treatments were also significantly different ($F = 32.15$; df = 3, 44; $p < 0.001$) (Table. 2). From pirimicarb-treated mummies, the cumulative emergence of *A. asychis* was 73.3%, not significantly different from the untreated control (81.7%) but significantly different from those treated with methamidophos (49.2%) or disulfoton (6.7%). There was also a significant difference in cumulative emergence between methamidophos and disulfoton treatments. The first emergence of *A. asychis* was observed from water-treated control mummies, followed by emergence from pirimicarb and methamidophos treated mummies. Parasitoids first emerged from disulfoton-treated mummies 6 d after treatment.

**Table 2.**

Daily and cumulative emergence (mean ± SD) of *A. asychis* from *M. persicae* mummies treated with disulfoton, methamidophos, and pirimicarb.

| Treatment | n | Daily emergence (%) | Cumulative emergence (%) |
|---|---|---|---|
| Water control | 12 | 6.81 ± 5.67a | 81.67 ± 15.86a |
| Pirimicarb | 12 | 6.11 ± 5.60a | 73.33 ± 21.88a |
| Methamidophos | 12 | 4.10 ± 4.17b | 49.17 ± 29.68b |
| Disulfoton | 12 | 0.56 ± 0.86c | 6.67 ± 8.88c |

Values within a column followed by the same letter are not significant ($p > 0.05$, Duncan's multiple range test, PROC GLM; SAS Institute, 1989)

There have been many studies of toxicity of insecticides to the nymphs or adults of *M. persicae*, but we are not aware of a comparative study on the effect of insecticides on *A. asychis* larvae inside *M. persicae* mummies. Although parasitoid larvae are not directly exposed to insecticides, those in newly-formed mummies may be more susceptible to insecticides than those inside older mummies. The significant differences in cumulative emergence rates showed the different degree of comparative toxicity of three insecticides to *A. asychis* inside 7 - 8 d old mummies after complete mummification. The cumulative emergence from mummies treated with the three insecticides indicate that pirimicarb is the least toxic to larvae of *A. asychis* followed by methamidophos and disulfoton. Pirimicarb controls aphids effectively with minimal effect on Aphelinid parasitoids (Helgesen and Tauber 1974, Zchori-Fein *et al.* 1994). Lecrone and Smilowitz (1980) reported that pirimicarb is less toxic than carbaryl and methamidophos to beneficial insects and more toxic to *M. persicae*. The application of pirimicarb to the aphid should help conserve natural enemies. Due to the reduced susceptibility to pirimicarb of *A. asychis* larvae inside *M. persicae* mummies, its role as a biocontrol agent in IPM programs will be improved if pirimicarb is applied during the larval development of *A. asychis*.

**Potential of *Aphelinus asychis* as a biocontrol agent.** Although foliar sprays of all the test insecticides (methamidophos, disulfoton, and pirimicarb) reduce the population size and probing times of *M. persicae* (Sandvol *et al.* 1980, Lowery and Boiteau 1988), early studies (Powell and Mondor 1973, Kirpes *et al.* 1982, Lowery *et al.* 1990) showed that the use of any one of these chemicals alone failed to suppress spread of potato viruses and recommended that the combined use of systemic insecticides with foliar sprays would be the most effective way to reduce virus spread. However, this would increase the control costs of *M. persicae* to twice that incurred by use of only one chemical (Kirpes *et al.* 1982). More seriously, development of resistance to pesticides by reduce the effectiveness of chemical control programs. It is becoming necessary to find control measures that are compatible with biological methods. From this point of view, integration of biological and pest-specific chemical control must be one of the strategies used to minimize problems in controlling *M. persicae*. The effective use of a selective

aphicide such as pirimicarb is an essential tool for use of integrated control methods, and early innundative release of *A. asychis* should delay the growth of the *M. persicae* population.

One of the characteristics of an effective biological control agent is adaptability to a wide range of environmental conditions (Huffaker *et al.* 1971). We find that *Aphelinus asychis* have adapted well to *M. persicae* in outdoor cages in a wide range of environments, during the early spring and the summer in WA. The most successful parasitoids are those that can exploit their host without leading to its extinction (Wyatt 1985), and this parasitoid might have few natural enemies due to its "exotic" nature. The high degree of parasitism and survival of *A. asychis* larvae inside the mummies treated with the selective aphicide pirimicarb, show its potential as a good biocontrol candidate in an IPM program to control *M. persicae*.

## ACKNOWLEDGEMENT

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# Carabid beetles in commercial raspberry fields in the Fraser Valley of British Columbia and a sampling protocol for *Pterostichus melanarius* (Coleoptera: Carabidae)

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## ABSTRACT

Carabid beetles were sampled in 15 raspberry fields in the Fraser Valley of BC from April to September, 1994. At least 28 species were caught, but one, *Pterostichus melanarius* (Illiger), dominated with 80% of all individuals. Eight of the nine most numerous species (>200 individuals caught) were introduced in North America. Significant, 30-fold differences were detected between fields with respect to abundance of seven of these species. The differences could not be attributed to soil type, type of habitat at the edge of the field nearest the traps, or spray history. A sampling protocol for pest managers was developed in which 1 to 3 consecutive weekly samples during July provide a relative index of annual abundance of *P. melanarius* throughout the season. Traps should be set at a standard distance from the edge of a field because numbers increase with distance from the edge. At least 10 traps per field are required for reasonable precision.

**Key words:** Carabidae, raspberry, sampling, *Pterostichus melanarius*, predator

## INTRODUCTION

Raspberry is an important crop in the Pacific Northwest. It is attacked by a number of key pests, including *Otiorhynchus sulcatus* (F.) (Coleoptera: Curculionidae), *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae) and other weevils and lepidoptera. These pests are in turn attacked by carabid beetles at some point in their life cycles. Thiele (1977) suggests that the assemblage of carabids that occur in any given area depends largely on the plant community. Raspberry pest management could therefore benefit from cultural practices that alter the habitat of carabids in ways that increase their predatory capacity. Raspberry fields provide a unique opportunity for cultural manipulations because there is considerable land to work with (rows are spaced 3 m apart), the soil between the rows may or may not be cultivated, annual or perennial cover crops may or may not be planted between the rows, and a planting may last for 35 years or more. Furthermore, the crop is grown over a large geographical area from Oregon, north to British Columbia, with a wide range of conditions over which to test cultural manipulations. This approach has been studied in other agricultural systems. Diversified agroecosystems appear to have positive effects on predacious and parasitic insects, including carabid beetles (Nentwig 1988; Thomas *et al.* 1991; Lys *et al.* 1994). Direct demonstration that this effect decreases pest populations is so far lacking, but work using other techniques has shown the importance of carabid beetles in regulating pests such as aphids (e.g. Edwards *et al.* 1979)

and root maggots (e.g. Grafius and Warner 1989).

Our first concern was to determine the nature of the existing carabid assemblage. Levesque and Levesque (1994) report on carabids found in a single raspberry plantation and adjacent sites in southern Quebec. Here, we report on carabids found in 15 commercial raspberry fields that extend from Westham Island to Sumas Prairie (about 75 km) in the Fraser Valley of BC: the species observed; their relative numbers; differences in numbers of the dominant species between fields, soil types, adjacent habitats and spray histories; and the effect of trap location and time of season on the number of carabids caught. These data are essential to plan future cultural manipulations and develop sampling protocols for pest managers.

**Table 1.**

Some characteristics of 15 commercial raspberry fields in the Fraser Valley, BC sampled for carabid beetles in 1994.

| Field | Location | Margin[1] vegetation | Soil symbol[2] | group[3] | Pesticide[4] |
|---|---|---|---|---|---|
| 1 | Sumas | forest | BT | 1 | 2 |
| 2 | Abbotsford | forest | MH-AD | 2 | 4 |
| 3 | Abbotsford | forest | MH | 2 | 4 |
| 4 | Clearbrook | forest | MH | 2 | 2 |
| 5 | Clearbrook | grass | MH | 2 | 3 |
| 6 | Clearbrook | raspberry | MH-AD | 2 | - |
| 7 | Clearbrook | forest | MH | 2 | 2 |
| 8 | Clearbrook | grass | AD | 3 | 3 |
| 9 | Clearbrook | raspberry | AD | 3 | 2 |
| 10 | Clearbrook | raspberry | AD | 3 | 3 |
| 11 | Clearbrook | raspberry | AD | 3 | - |
| 12 | Langley | forest | W-AB | 4 | 4 |
| 13 | Langley | forest | W-SC | 4 | 4 |
| 14 | Westham Island | grass | WS | 5 | - |
| 15 | Westham Island | raspberry | WS-CT | 5 | 1 |

[1] Margin nearest traps. Adjacent grass was usually ploughed during the season.
[2] BT, Bates, medium-textured, imperfect drainage; MH, Marble Hill, medium-textured, well drained; AD, Abbotsford, medium-textured, well to rapid drainage; W, Watcom, moderately fine textured, moderately well drained; AB, Albion, moderately fine to fine textured, moderately poor to poor drainage; SC, Scat, moderately fine textured, poor drainage; WS, Westham, moderately fine to medium-textured, poor to moderately poor drainage; CT, Crescent, medium to moderately fine textured, moderately poor to poor drainage, (Luttmerding 1980, 1981).
[3] Soil grouping for analyses.
[4] 1, no insecticides; 2, Diazinon; 3, Diazinon and Malathion; 4, Diazinon and Guthion or Furadan; -, unknown.

## MATERIALS AND METHODS

Commercial raspberry fields were chosen from a wide range of ecological and cultural situations in the Fraser Valley (Table 1). These fields were sampled continuously from 26 April to 28 September 1994 using pitfall traps. The beetles were collected and the traps cleared weekly until 30 August, and then bi-weekly until 28 September. Pitfall traps were made from tapered plastic beer cups (9.5cm diam top). A hole (1.6 cm diam) was cut in the bottom centre of pairs of cups. One cup was sunk in the soil with the rim just below the soil surface, to form a mould. Lumite Saran screening (13 x 13 threads/cm) was glued over the hole in the other cup using contact cement. The screen kept smaller carabids like *Bembidion* spp. from escaping, but allowed water through. The screened cup was placed inside the first, mould cup, so that the soil was level with the rim. This second cup was easily removed to empty the trap. The traps were

placed between raspberry plants within a row, where they did not interfere with daily farm operations. Five traps were located 6 m apart, within 2 m of an edge of a field, and five more were located 6 m apart, within 50 m of the same edge. A plywood cover (10.5 x 10.5 x 1.7 cm), supported by wire (9 cm x 1.5 mm diam) driven into the wood at the four corners, was set in place 4 cm above each cup to reduce contamination from leaf litter.

A reference collection of carabids was developed with material identified at the Biosystematics Research Centre (BRC), Agriculture Canada [now the Eastern Cereal and Oilseed Research Centre (ECORC), Agriculture and Agri-Food Canada] in Ottawa. Identification was based on Hatch (1953). Most beetles were identified in the field, but specimens that were in doubt were brought back to the laboratory for closer examination, and sent to BRC for identification when necessary. Beetles caught in the pitfall traps were released several kilometres from the study field to eliminate the possibility of recapture.

Regression, ANOVA and chi-square (SAS Institute Inc. 1990) were used to analyze the data. Catches from each trap were summed over time for all analyses except those relating to temporal activity. Regression of ln(variance) on ln(mean), of data from the five traps at each location in a field was used to determine the appropriate transform according to Southwood (1966); data are reported on both transformed and back-transformed scales (Fig. 1). Differences in beetle numbers between fields were tested using the trap-location-within-field residual mean square; and differences between environmental categories (soil type, adjacent habitat and spray history) were tested using their respective field-within-category residual mean square.

## RESULTS AND DISCUSSION

At least 28 carabid species were caught in the commercial raspberry fields (Table 2). These species have a wide range of prey: *Bembidion* species - insect eggs (van Dinther and Mensink 1971); *Calathus fuscipes* (Goeze) and *Pterostichus melanarius* (Illiger) - caterpillars, aphids and weevils (Skuhravý 1959); *Carabus* species - arthropods and earthworms (Thiele 1977). *Carabus granulatus* L. also eats slugs (Scherney 1955). Eight of the nine most abundant species (>200 individuals caught) were introduced in North America. The dominant species was *P. melanarius* with 30984 individuals caught in 3404 trap-weeks (number of traps x weeks). The next most abundant species was *C. fuscipes*, with 1,975 individuals. This is a typical dominance structure associated with reduced habitat variation on agricultural land - "few species definitely playing a leading role" (Thiele 1977). Levesque and Levesque (1994) observed a similar dominance structure in a raspberry field in Québec. The assemblage of beetles was different, but as in our study, most were *P. melanarius*. Fourteen species and *Amara* spp. were active during the entire sampling period. However, each species had a period of peak activity, either during April-May or August-September (Table 2).

Data for the nine species (and *Amara* spp.) with more than 200 individuals caught during the sampling period were analyzed statistically. There were significant differences between fields with respect to the number of individuals of *Amara* spp., *Anisodactylus binotatus* (F.), *Bembidion dyschirinum* LeConte, *Calathus fuscipes*, *Carabus nemoralis* O.F. Müller, *C. granulatus*, *Pterostichus melanarius* ($F = 6.0$-$37.4$; df = $14,15$; $p < 0.01$; e.g. Fig. 1), and *Clivinia fossor* (L.) ($F = 3.2$; df = $14,15$; $p < 0.05$), but not with respect to *Harpalus affinis* (Schrank) and *Trechus obtusus* Erichson ($F = 1.3$-$1.6$; df = $14,15$; $p > 0.05$). So differences between fields were detected for most of the species tested, and the differences were large - in the order of 30-fold or more (back-transformed scale, Fig. 1). Furthermore, the pattern of species dominance was not the same from field to field ($\chi^2 = 55688$; 126 df; e.g. Fig. 1).

The differences between fields could not in general be attributed to soil type, adjacent habitat or spray history (21 out of 24 tests; $p > 0.05$). This is surprising - Thiele (1977) suggests that soil, heavy (clay) *vs.* light (sandy), has an overriding quantitative and qualitative effect on carabid
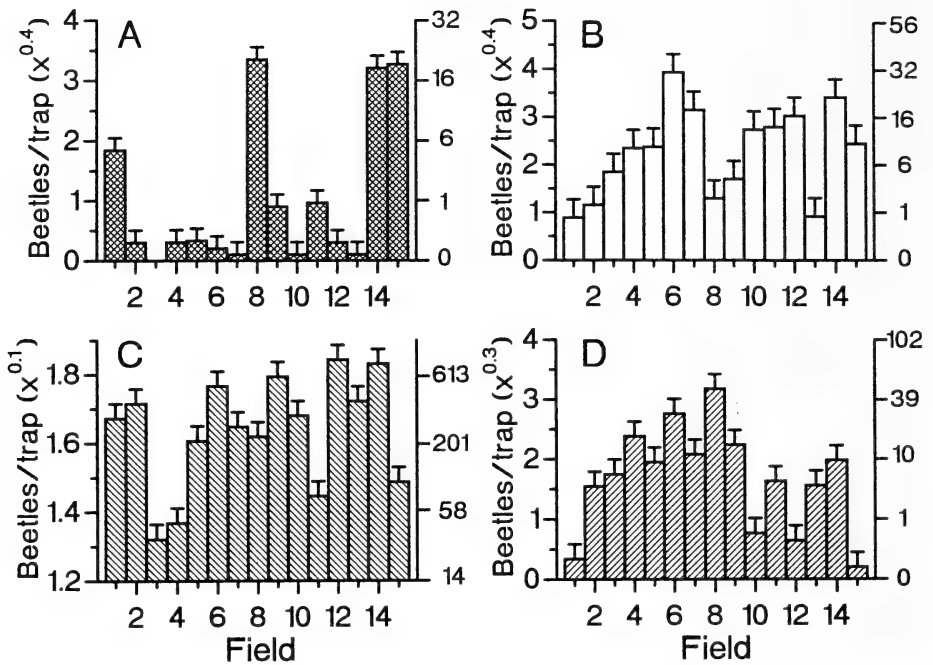
**Figure 1**. Mean number of carabid beetles per pitfall trap in 15 commercial raspberry fields in the Fraser Valley, BC, from April to September 1994: **A**, *Carabus granulatus*; **B**, *Bembidion dyschirinum*; **C**, *Pterostichus melanarius*; **D**, *Calathus fuscipes*. Fields numbered as in Table 1; vertical axes on right in back-transformed scale; vertical bars are +1SE on transformed scale.
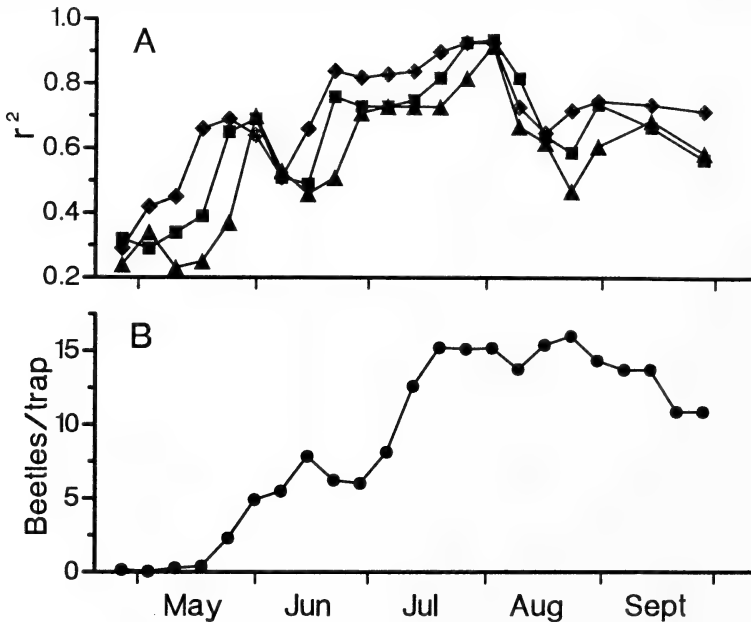


**Figure. 2**. Correlation coefficients between the number of *Pterostichus melanarius* caught per pitfall trap [summed over 1- (triangle), 2- (square), and 3- (diamond) consecutive weekly samples] and number caught per pitfall trap summed over entire sample period - data for 15 raspberry fields in the Fraser Valley, BC, **A**; and number of *P. melanarius* per pitfall trap during the season, **B**.

populations. In our study, however, there was large variation between fields within a category [e.g. Fig. 1C, fields 14-15 have similar soils, but very different numbers of *P. melanarius*, so the power of the test was low ($< 0.2$)]. Insufficient degrees-of-freedom and non-orthogonality precluded analyzing the three factors simultaneously. The magnitude of the unexplained differences between fields suggest that further work is warranted to determine the cause. Any factors that can be manipulated culturally could be used to increase the predatory capacity of the carabid assemblage.

**Table 2.**

Carabids in pitfall traps in 15 commercial raspberry fields, Fraser Valley, BC. Ten traps in each field were checked and cleared weekly (26 Apr. - 30 Aug.), or bi-weekly (30 Aug. - 28 Sept.) 1994. Missing data, 46 out of 3450 trap-weeks

| Species[1] | Total trapped | Observations first | last | Greatest abundance[2] Period | Total | N[3] |
|---|---|---|---|---|---|---|
| *Agonum muelleri* (Herbst)+ | 42 | 26/04 | 28/09 | 09/08 - 30/08 | 22 | 440 |
| *Agonum subsericeum* (LeConte) | 9 | 26/04 | 13/07 | | | |
| *Amara* spp. | 561 | 26/04 | 28/09 | 19/04 - 10/05 | 330 | 440 |
| *Anisodactylus binotatus* (Fabricius)+ | 1190 | 26/04 | 28/09 | 03/05 - 24/05 | 378 | 430 |
| *Bembidion dyschirinum* LeConte | 1744 | 26/04 | 28/09 | 19/04 - 10/05 | 1471 | 440 |
| *Bembidion iridescens* (LeConte) | 1 | 26/04 | 26/04 | | | |
| *Bembidion obscurellum* (Motschulsky)* | 7 | 26/04 | 08/06 | | | |
| *Bembidion tetracolum* Say+ | 20 | 26/04 | 24/08 | 19/04 - 10/05 | 8 | 440 |
| *Bradycellus congener* (LeConte) | 7 | 26/04 | 26/04 | | | |
| *Calathus fuscipes* (Goeze)+ | 1975 | 26/04 | 28/09 | 23/08 - 13/09 | 796 | 445 |
| *Carabus nemoralis* O.F. Müller+ | 280 | 26/04 | 28/09 | 19/04 - 10/05 | 125 | 440 |
| *Carabus granulatus* Linneaus+ | 727 | 26/04 | 28/09 | 19/04 - 10/05 | 326 | 440 |
| *Cicindela oregona* LeConte | 3 | 04/05 | 07/06 | | | |
| *Clivina fossor* (Linneaus)+ | 215 | 26/04 | 28/09 | 19/04 - 10/05 | 117 | 440 |
| *Cychrus tuberculatus* Harris | 1 | 24/05 | 24/05 | | | |
| *Dyschirius globulosus* (Say) | 9 | 26/04 | 28/06 | | | |
| *Harpalus affinis* (Schrank)+ | 290 | 26/04 | 28/09 | 19/04 - 10/05 | 131 | 440 |
| *Harpalus cordifer* Notman | 33 | 26/04 | 28/09 | 03/05 - 24/05 | 19 | 430 |
| *Loricera pilicornis* (Fabricius)* | 80 | 26/04 | 28/09 | 19/04 - 10/05 | 55 | 440 |
| *Notiophilus directus* Casey | 63 | 26/04 | 28/09 | 19/04 - 10/05 | 37 | 440 |
| *Omus dejeani* Reiche | 2 | 26/04 | 24/05 | | | |
| *Patrobus fossifrons* (Eschscholtz)* | 1 | 24/08 | 24/08 | | | |
| *Promecognathus crassus* LeConte | 1 | 24/05 | 24/05 | | | |
| *Pterostichus adstrictus* Eschscholtz* | 15 | 26/04 | 28/09 | 19/04 - 10/05 | 12 | 440 |
| *Pterostichus melanarius* (Illiger)+ | 30984 | 26/04 | 28/09 | 09/08 - 30/08 | 6857 | 449 |
| *Pterostichus patruelis* (Dejean) | 3 | 26/04 | 11/05 | | | |
| *Synuchus impunctatus* (Say) | 1 | 20/07 | 20/07 | | | |
| *Trechus obtusus* Erichson+ | 283 | 26/04 | 28/09 | 06/09 - 28/09 | 124 | 428 |

[1] * Holarctic; + Introduced in North America (Bousquet 1991).
[2] Greatest number of beetles per trap during 3 sequential weeks.
[3] Number of traps x weeks.

Given the differences between raspberry fields with respect to carabid beetles, it would be useful for pest managers to monitor these beneficial insects. The data obtained annually could be combined with information about the pests, and laboratory studies, to develop pest management strategies. We suggest that *P. melanarius* should be monitored. It is the most abundant species; it is easy to identify in the field; it ingests up to nine-tenths animal matter in its diet (Thiele 1977); preys on the key pests of raspberry (among other prey); and it can consume more than three times its own weight per day (Scherney 1959). Furthermore, the differences in *P. melanarius* populations between fields provide a ready-made framework for comparative

studies.

Probably the most important constraint from the point of view of a pest manager is time; sampling protocols must be quick, yet provide a picture of the dynamics of pests and beneficials within a field. *Pterostichus melanarius* is a univoltine, "autumn-breeding" species (Thiele 1977), and as such, a well-timed pitfall sample should give a reasonable picture of relative population size in a field. However, the situation is complicated by the fact that some reproductive females survive the winter and reproduce again the following year. Basedow (1994) found that old females laid eggs in early June; new females began emerging at this time and laid eggs through late June and July (data were not collected in August and September). Our study suggested that the best estimate of annual abundance among fields with very different *P. melanarius* populations (Fig. 1C) could be obtained by pitfall trapping during 1-3 consecutive weeks from late June to late July. During this time, total trap catches of *P. melanarius* were most highly correlated with weekly catches (Fig. 2A). Although the result can be partially explained in terms of auto-correlation, there are periods when beetle numbers are low (Fig. 2B) but the correlation coefficient is relatively high and vice versa - early May, early June and August. The temporal variation in the correlation coefficients may be related to the phenology of the beetle, in particular the appearance of old females in May, and new females in June (Basedow 1994); the decline of the correlation coefficient in August may be related to variation in cultural practices such as cultivation after harvest. It is clear, however, that samples should be taken during the same time period when making comparisons between fields with respect to the annual abundance of *P. melanarius*. The best sampling time is probably during July when new adults have emerged and before post-harvest cultivation. Comparisons of samples between years may be misleading because year-to-year differences in factors such as weather and temperature will affect activity levels and hence the numbers caught.
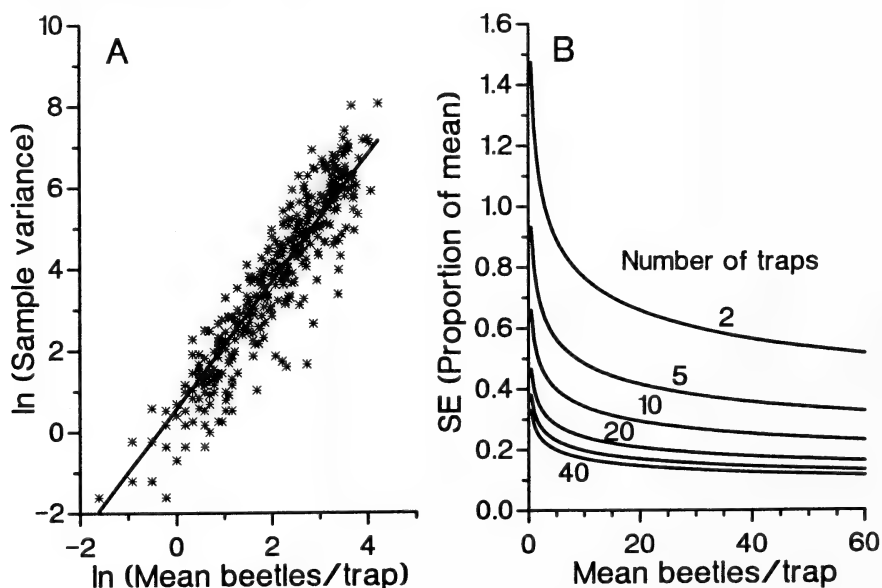


**Figure. 3**. Relationship between ln(sample variance) ($y$) and ln(mean) ($x$), ($y = 0.566 + 1.563$ $x$; respective SE's for coefficients: 0.0429 and 0.0204; remainder mean-square = 0.5212) based on weekly collections from five pitfall traps at each location in a field, **A**; and effect of number of traps and mean number of beetles per trap on standard error, expressed as a proportion of the mean **B**; data for *Pterostichus melanarius*.

Traps should be set at a standard distance from the edge of a field. Fewer *P. melanarius* were caught in traps 2 m from the edge of a field adjacent to forest or grass than at 50 m (average slope = 1.47 beetles/trap per m; SE = 0.53; n = 10). Standardizing the location of the traps will reduce some of the variation in the estimate of beetle numbers and facilitate field-to-field comparisons.

At least 10 traps are required for reasonable estimates of carabid numbers in a field. The relationship between ln(variance) and ln(mean) of five pitfall-trap catches of *P. melanarius* at 2 and 50 m in all fields during 1-week sampling intervals (Fig. 3A) was used to determine the standard error of the mean - as a proportion of the mean - for increasing numbers of traps (Fig.3B). Two traps would provide a very crude estimate of carabid populations. At 10 traps per field, 3-fold population differences could be detected (above 10 beetles per trap). Differences between fields may be as great as 30 fold, so that 10 traps should provide an adequate level of precision for management purposes.

Pitfall-trap data must be viewed cautiously when comparing species abundance across habitats, but it is well suited to studies on the impact of predators in agricultural situations (Spence and Niemela 1994). We show several ways of standardizing pitfall trapping for studies of *P. melanarius* in raspberry fields. The analyses are based on pitfall data from British Columbia, but the conclusions will probably also apply in the State of Washington, at least near the border. Comparative studies on farms near the border could provide information about the effect of different farm practices on carabid populations, in particular, chemical controls.

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# Distribution of two European wireworms, *Agriotes lineatus* and *A. obscurus* in British Columbia

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## ABSTRACT

We determined the distribution of two European wireworms, *Agriotes lineatus* and *A. obscurus*, in the Fraser Valley of BC. *Agriotes obscurus* is now present in farmland between Delta and Laidlaw, and the range of *A. lineatus* has expanded from Vancouver Island to the lower Fraser Valley between Delta and Vancouver. The first record of *A. obscurus* in Washington State was made in Lynden in 1997.

**Key words**: Wireworms, Elateridae, *Agriotes lineatus, A. obscurus*

## INTRODUCTION

Of 369 species and subspecies of wireworms (family Elateridae) found in Canada, 194 occur in British Columbia (Bousquet 1991). Of these, at least 27 species are associated with agricultural land, but only eight are considered pests (Wilkinson 1963). Endemic species of wireworms of potential agricultural concern in BC are: *Agriotes sparsus* LeConte, a pest of potatoes in the lower Fraser Valley; *Limonius canus* LeConte and *L. infuscatus* Motschulsky, pests of vegetables on Vancouver Island, the lower Fraser Valley, and the Okanagan and Kootenay Valleys; *Ctenicera aeripennis* (Kirby) and *C. destructor* (W. J. Brown), widespread pests of grain and vegetables in BC; and *C. lobata* (Eschscholtz), a pest of potatoes in the lower Fraser Valley (Wilkinson 1963).

Two additional species, *Agriotes lineatus* (L.) and *A. obscurus* (L.), were introduced into BC from Europe, probably around 1900, and are now established on Vancouver Island and in the Fraser Valley (Wilkinson 1963, 1980). These European wireworms are considered common pests of agricultural crops in Europe and Asia (Eidt 1953), and Wilkinson (1980) predicted they would become serious threats to agriculture in BC. *Agriotes lineatus* was first discovered in BC near Cobble Hill on Vancouver Island (King 1950), and by 1980 was known to have spread to Vancouver in the lower Fraser Valley (Wilkinson 1980). *Agriotes obscurus* was also reported from Cobble Hill (King 1950), and was found in 1952 at the eastern end of the Fraser Valley near Agassiz (King *et al*. 1952). By 1980, *A. obscurus* had been reported from several farms in Surrey (Cloverdale), about 70 km west of Agassiz (Wilkinson 1980). Since then, no reports of the distribution of *A. obscurus* or *A. lineatus* in BC have been published.

In recent years, wireworm damage has increased dramatically in small fruit, vegetable and ornamental crops throughout the Fraser Valley. The damage appears to have been caused by *A. obscurus* or *A. lineatus* or both (Vernon, unpublished data) but because these species are extremely difficult to identify using larval characteristics alone (Wilkinson, 1963), it is not certain what species are damaging crops in certain areas. This is especially true for the Delta and

Abbotsford regions, where wireworm damage to crops has been severe, but neither *A. obscurus* nor *A. lineatus* has been previously recorded.

Because most effective insecticides for wireworm control have been withdrawn from use in BC, alternative management approaches are being investigated.     To control *A. obscurus* in the Agassiz region, for example, trap crops for the larvae and devices for mass trapping walking adult elaterid beetles are being tested (Vernon, unpublished data).  Behaviour and host preference of different species of wireworms vary.  Consequently, different control strategies may be needed for different species in different areas.  Before deciding which methods to use to control *A. obscurus* and *A. lineatus*, we checked their present distribution in the Fraser Valley, suspecting that their ranges had expanded since Wilkinson's survey in 1963.  We examined previously collected and identified adult elaterid specimens in the collection of the Pacific Agri-Food Research Centre (PARC) in Agassiz, and adults collected in pitfall trap surveys in 1996 and 1997.  In 1996, 26 pitfall traps were placed in three fields in Westham Island, 33 traps in two fields in Ladner (both of these locations in the Municipality of Delta in the lower Fraser Valley), 20 traps in three fields in Abbotsford (central Fraser Valley), and 6 traps in two fields in Agassiz (upper Fraser Valley).  In 1997, 8 pitfall traps were established in Langley and 10 traps in Lynden, Washington.  Sub-samples of elaterid beetles collected in 1996 were identified to species by Dr. Ed Becker at the Biosystematics laboratory in Ottawa.  From these collections and previously published data, the known ranges of *A. lineatus* and *A. obscurus* in the Fraser Valley of BC and northwestern Washington are as follows. (Figure. 1):
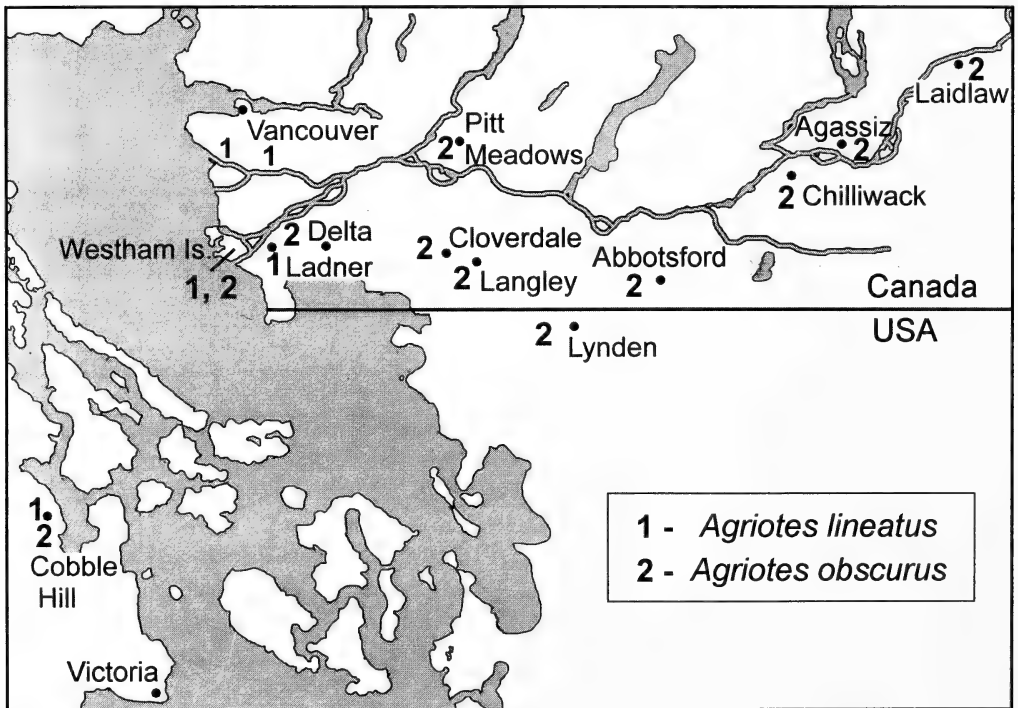


**Figure 1.** Map of regions of the Fraser Valley and Vancouver Island, BC, and Washington state, where *Agriotes obscurus* and/or *A. lineatus* have so far been confirmed.

*Agriotes lineatus*: Cobble Hill (King 1950); Vancouver (South and West Vancouver, Wilkinson, 1980); Burnaby (PARC, Agassiz collection, 1980); Delta (Ladner and Westham Island, 1996 survey).

*Agriotes obscurus*: Cobble Hill (King, 1950); Agassiz (King *et al.* 1952);˙Chilliwack (PARC, Agassiz collection, 1953); Laidlaw (PARC, Agassiz collection, 1973); Surrey (Cloverdale, PARC, Agassiz collection, 1973); Pitt Meadows (PARC, Agassiz collection, 1981); Abbotsford (1996 survey); Delta (Ladner and Westham Island, 1996 survey); Langley (1997 survey); Lynden, WA (1997 survey).

This survey was not exhaustive, but does show that *A. lineatus* has now become established in prime agricultural regions in Delta (Ladner and Westham Island). The highest numbers of *A. lineatus* were found in pitfall traps in Ladner surrounding a potato field that had previously been heavily damaged by *Agriotes* wireworms in 1994. No *A. lineatus* have been found east of Ladner in Delta. *A. obscurus* has been found in several locations as far west as Ladner and Westham Island, and as far east as Laidlaw. Specimens of *A. obscurus* were identified for the first time in Abbotsford in 1996, and in Langley, BC and Lynden, WA in 1997. *Agriotes obscurus* appears to be steadily moving westward from its original discovery in the upper Fraser Valley in Agassiz, and *A. lineatus*, now in the Fraser Valley, has moved eastward from its hypothetical starting point on Vancouver Island. The only region of overlap between the two species in the Fraser Valley was in Ladner and Westham Island in Delta. The single specimen of *A. obscurus* caught in a pitfall trap in a field of raspberries in Lynden is the first recorded occurrence of this species in Washington State.

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# Topical application of carbon dioxide and liquid nitrogen against the mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae)

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## ABSTRACT

A small-scale field experiment was conducted near Prince George to evaluate the effectiveness of topical treatments with $CO_2$ and liquid $N_2$ for killing brood in lodgepole pine trees infested with the mountain pine beetle, *Dendroctonus ponderosae* Hopk. (Coleoptera: Scolytidae). $CO_2$ and liquid $N_2$ caused significant ($p < 0.05$) mortality of approximately 40% and 60 - 63 % of larvae and adults, respectively. About \$263 and \$67 worth of $N_2$ and $CO_2$, respectively, would be needed to treat 1.5 m of the trunk of an infested tree. The low mortality and high treatment costs make freezing uneconomical compared to the alternatives of monosodium methane arsonate or felling and burning.

**Key words**: mountain pine beetle, *Dendroctonus ponderosae*, liquid nitrogen, carbon dioxide, control techniques

## INTRODUCTION

The mountain pine beetle, *Dendroctonus ponderosae* Hopk. kills many trees in the Prince George Region, affecting 25400 ha of lodgepole pine, *Pinus contorta*, in 1995 (Taylor 1996). Logging infested trees and treating individual trees are the most common direct control techniques. Two common treatments include the use of the systemic pesticide MSMA (monosodium methane arsonate) and "fall & burn"(Safranyik *et al.* 1982). MSMA must be applied within 3 weeks of attack for maximum effectiveness (Dyer and Hall 1979). In addition, opposition to the use of pesticide has sometimes precluded or limited its use, and current guidelines prevent the commercial use of trees treated with MSMA. Felling and burning infested trees is very costly and also prevents their commercial use. There is a need for inexpensive and non-toxic alternatives to both MSMA and "fall & burn", especially in parks and riparian areas.

The use of freezing to kill insect pests is well known, especially for stored product and structural pests (Forbes and Ebeling 1986). Promising results were also found in a trial against *Ips typograpus* L. in Romania (Hristea, personal communication 1996), in which liquid $N_2$ was pumped into a sleeve encasing an infested spruce tree. $CO_2$ and liquid $N_2$ come out of their containers at -79°C and -196°C respectively (Weast *et al.* 1984), and therefore can decrease the temperature of a surface well below the lethal level of -38°C for winter hardened larvae (Safranyik 1985). In summer the larvae would not be as cold

hardy. We conducted a preliminary assessment of $CO_2$ and liquid $N_2$ as topical sprays to control the mountain pine beetle.

## METHODS

On October 3, 1996, eight trees (mean diameter ± SD at breast height (1.3 m) = 48.6 ± 5.9 cm) infested with mountain pine beetle were selected near Prince George. The trees were felled and the infested portion of the bole identified. Three 20 x 20 cm (400 cm²) treatment sites were marked 1 m apart on each tree and randomly given either: no treatment; a 30 second application of liquid $N_2$ (about 2.33 l); or a 30 second application of $CO_2$ (about 540 g). Liquid $N_2$ was applied using a 125 l cylinder or a 35 l cylinder (for transport to distant trees) coupled to a 4 m hose with a "snowhorn" nozzle attached. For the $CO_2$ treatment a 23 kg cylinder with a liquid withdrawal system was used[1]. Delaying treatment until 3 October allowed time for eggs to hatch and larvae to start developing after an unseasonably late attack in September. Samples were cut out with a chisel up to 4 days after treatment and the patches were allowed to warm up for 2 to 3 weeks at room temperature before examination. Larval, pupal and adult mortality was assessed as bark was removed from samples. Larvae were placed in 95% ethanol for measuring head-capsule widths. For each sample, thickness of the bark (phloem plus cortex) was measured in three places with a vernier calliper.

Mean percent mortalities for adults and larvae were compared by a one way analysis of variance (ANOVA). Linear regression analysis ($\alpha = 0.05$) was conducted to relate bark thickness to percent larval mortality for the three treatments using the equation: $y = a + bx + e$, where y is the percent larval mortality, a is a regression constant, b is bark thickness in mm and e is an error term. To determine costs of both the $CO_2$ and $N_2$ treatments the cost of treating 400 cm² was extrapolated to a 1.5 m length of infested bole with a diameter of 50 cm.

## RESULTS

Less than 10% of the larvae and adults were dead in the untreated bark. $CO_2$ killed 54.5% of the larvae and 54.7% of the adults, subtracting the control mortality. Liquid $N_2$ killed significantly more larvae (63.2%, $F(2,21) = 6.643$ $p = 0.006$) and adults (60.5%, $F(2,16) = 5.771$ $p = 0.013$) than the control treatment (Table 1).

### Table 1
**Comparison of mean mortalities caused by topical sprays of $CO_2$ and liquid $N_2$ on the outer bark of trees infested by mountain pine beetles**

| Life Stage | Treatment | No. of replicates | No. per m² (± SD)[a] | % mortality (± SD)[a] |
|---|---|---|---|---|
| **Larvae** | Untreated control | 8 | 37.9 ± 17.9 a | 8.7 ± 7.8 a |
| | Carbon Dioxide | 8 | 30.9 ± 17.9 a | 40.1 ± 27.0 ab |
| | Nitrogen | 8 | 57.6 ± 25.3 b | 63.2 ± 43.7 b |
| **Adults** | Untreated Control | 7 | 3.0 ± 1.5 a | 4.8 ± 12.6 a |
| | Carbon Dioxide | 5 | 1.0 ± 0.0 b | 40.0 ± 54.8 ab |
| | Nitrogen | 7 | 2.9 ± 1.3 ab | 60.5 ± 44.7 b |

[a] Means for each life stage followed by the same letter are not significantly different, Tukey's test, $p=0.05$.

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[1] Praxair, Delta, BC, gases and equipment.

There was an inverse relationship between bark thickness and percent larval mortality for the $N_2$ treatment. The regression for mortality was 148.8 - 17.9 x (bark thickness in mm), $r^2 = 0.744$, adjusted $r^2 = 0.479$, $F(1,6) = 7.439$, $p = 0.034$ (Fig. 1). The regression was not significant for the control ($F(1,5) = 1.369$, $p = 0.295$) or the $CO_2$ treatments ($F(1,5) = 1.881$, $p = 0.228$).
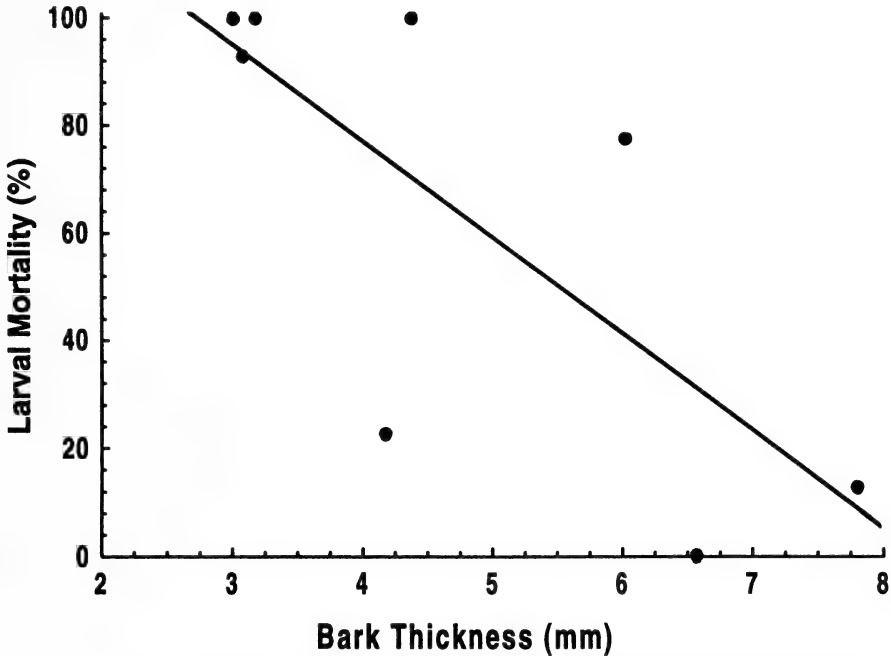


**Figure 1**. The relationship between bark thickness and larval mortality for the liquid $N_2$ treatment. Line plotted from the regression y = 148.8 - 17x, ($r^2 = 0.744$, adjusted $r^2 = 0.479$, $p = 0.034$).

## DISCUSSION

Treatment with liquid $N_2$ causes significant mortality of both adult and larval mountain pine beetles. However, mortalities are about the same as those caused by a late MSMA treatment, which was 55% four weeks after attack (Dyer and Hall 1979). Moreover, the lower larval mortality under thick bark (Fig.1) shows: that liquid $N_2$ treatment may be ineffective on the large-diameter lodgepole pine trees with thick bark that are selected by the mountain pine beetle.

To treat about 2.3 m$^2$ of bark on the basal 1.5 m of the bole of the average tree in this study would require 128 l of $N_2$ or 30 kg of $CO_2$, costing $263 and $67, respectively. A further labour cost of $60 per tree would result in total application costs of $323 per tree for liquid $N_2$ or $127 for $CO_2$. In comparison, MSMA and fell & burn treatments, cost about $50 and $100, respectively. Unless their application rates can be reduced, or their efficacy increased, neither $CO_2$ nor $N_2$ is likely to be used operationally. One way to increase the effectiveness might be to delay treatments until spring when the brood may be less cold hardy than in the fall.

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# Predation on eggs of codling moth (Lepidoptera: Tortricidae) in mating disrupted and conventional orchards in Washington

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## ABSTRACT

Predation on eggs of codling moth, *Cydia pomonella* L., was assessed in Washington in June and August, 1995 in eight apple orchards treated with organophosphate insecticides (OPs), four orchards treated with mating disruption (MD) and some OPs, and four treated with MD but not with OPs. Sentinel codling moth eggs laid by caged moths on 10 shoots in each orchard were scored as alive, dead, or missing after 7 d, and beating tray samples of arthropod predators were collected at the beginning and end of each trial. Levels of egg predation (dead + missing eggs) did not differ significantly among orchard types in June but varied among orchard types in August (MD alone > MD + OPs > OPs). The percentage of dead eggs in August was significantly higher in the orchards receiving only MD than in orchards treated only with OPs. The percentage of missing eggs was significantly lower both months in orchards not treated with MD. Densities of spiders and all predators on both sample dates and for earwigs in August were significantly higher in orchards not treated with OPs. Densities of heteropteran predators did not vary significantly by orchard type. No significant correlations were found among predator densities and egg mortality within an orchard type. However, the percentages of dead eggs and dead plus missing eggs were significantly and positively correlated with densities of earwigs, spiders, and all predators in tray samples across the 16 orchards.

**Key words:** Codling moth, eggs, predation, mating disruption, biological control

## INTRODUCTION

Within six years of registration, the sex pheromone for mating disruption (MD) of codling moth, *Cydia pomonella* L., is being used on nearly 20% of the apples produced in Washington (Alway 1997). Successful use of sex pheromones to manage codling moth has relied on low initial moth densities and intensive population monitoring. Adoption of MD has reduced the use of the broad spectrum organophosphate insecticides (OPs) against codling moth in apples by 75 - 85% (Gut and Brunner 1994, Knight 1995). The use of MD in Washington's apple orchards has replaced between 1 and 3 applications of the OP, azinphosmethyl. However, 77% of orchards treated with MD are still sprayed with OP for codling moth (Alway 1997).

The effects of reducing the use of OPs in MD orchards on the biological control of secondary pests, such as leafrollers, leafminers, aphids, and leafhoppers have been documented (Gut and Brunner 1994, Knight 1995). In general, the effectiveness of biological control has increased after the adoption of MD, but in many cases, supplemental use of insecticides has still been required. For example, Knight (1995) found that growers reduced their use of sprays for these pests by only 18% during three years of MD. Interestingly, the effects of implementing MD in Washington's apple orchards on the biological control of codling moth itself have been overlooked.

Many parasitoids and predators are known to attack the various life stages of codling moth,

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including its egg (Falcon and Huber 1991). Previous studies of egg mortality of codling moth in Washington reported that parasitism by *Ascogaster quadridentatus* Wesmael occurs widely in unmanaged sites (crabapple and abandoned apple orchards) at low levels (< 20%), but was not detected in a survey of certified-organic orchards in the Yakima area before the adoption of MD (Knight 1994). In a more recent survey of conventional and organic orchards, egg parasitism by *Trichogramma* spp. was not observed (A.L.K., unpubl. data). These findings are consistent with a report by Yothers *et al.* (1935) that *Trichogramma* was not present 60 years ago in insecticide-managed apple orchards near Wenatchee, WA, even before the use of OPs.

There are no reports of predation on codling moth eggs in managed apple orchards in Washington. However, Ferro *et al.* (1975) found that 22% of eggs laid in an abandoned orchard near Ellensburg, WA were either nonviable, diseased, or presumed eaten by predators. Studies of egg predation in unsprayed orchards or in "integrated" or "biological control" orchards which were treated with a limited number of outdated materials, i.e., ryania, DDT, or lead arsenate, from other areas of the U.S., Canada, and Europe have found similar patterns. The major predators of codling moth eggs are anthocorids, mirids, earwigs, lacewings, and predatory thrips (Falcon and Huber 1991). Predation of codling moth eggs in unsprayed orchards generally removes 10 - 20% of eggs laid on leaves (Summerland and Steiner 1943, Westigard *et al.* 1976, Wood 1965), and 40 - 70% of eggs placed artificially (glued on leaves, shoots, and fruits) in the orchard (Glen 1975, 1977, Subinprasert and Svensson 1988). In comparison, egg predation in orchards sprayed with oil and early-season use of arsenical or botanical insecticides was usually 5 - 16% lower (Jaynes and Marucci 1947, MacLellan 1962, Wood 1965), but not always (Summerland and Steiner 1943). Levels of codling moth egg predation in orchards treated with OPs have not been reported.

We report the levels of predation of codling moth eggs and predator population densities in 16 apple orchards in Washington in 1995 treated with one of three regimes: conventional OP-based spray programs, MD supplemented with early-season OPs, or MD alone.

## MATERIALS AND METHODS

Sixteen orchards in central Washington were selected in 1995 based on their use of insecticides. Eight conventional orchards were treated with a typical broad spectrum insecticide spray program for apple in Washington (Beers and Brunner 1991). Insecticides used included: a delayed-dormant spray of chlorpyrifos (DowElanco, Indianapolis, IN) and superior-type oil, 3 - 5 sprays of azinphosmethyl (Bayer AG, Kansas City, MO) beginning at 250 degree days (temperature threshold = 10°C) after the first sustained codling moth catch; and, for secondary pests, an average of two neurotoxic insecticide sprays of one of the following compounds: phosphamidon (CIBA-GEIGY, Greensboro, NC), endosulfan (FMC Corp., Middleport, NY), formetanate hydrochloride (AgrEvo, Wilmington, DE), carbaryl (Rhone Poulenc Ag. Co., Research Triangle Park, NC), oxamyl (Dupont Inc., Wilmington, DE), phosmet (Gowan Co., Yuma, AZ), methyl parathion (Pennwalt Chemical Co., Philadelphia, PA) and dimethoate (American Cyanamid Co., Princeton, NJ). Eight MD orchards were treated with 1,000 ISOMATE-C+ dispensers per ha (Shin-etsu, Tokyo, Japan). The four MD plus insecticide orchards were treated with chlorypyrifos plus superior-type oil at the delayed-dormant stage and one spray of azinphosmethyl in late May. Secondary pests were controlled with either a commercial formulation of *Bacillus thuringiensis* Berliner (for leafrollers) or soap (for aphids and leafhoppers). The four MD orchards were either left unsprayed or treated only with superior-type oil at the delayed-dormant stage. All orchards were given several spray applications of micronutrients.

Egg predation was assessed in each orchard using sentinel eggs laid by moths from a laboratory colony. Cylindrical mesh sleeve cages (20 x 40 cm) were placed on one shoot on each

of 10 trees in each orchard. Three female moths (presumed mated) from a laboratory colony were placed in each cage for 1-2 d. Sleeves were removed, leaves with eggs were flagged, and a diagram of egg locations was drawn for each leaf. Leaves were removed from some shoots to ensure that no more than 10 eggs were present. Shoots were clipped after 7 d and examined in the laboratory. Eggs were scored as alive, dead, or missing. Dead eggs were characterized as being shriveled and flat in appearance. Field assays were started on 3 - 10 June and 10 - 17 August, 1995. Assays in the insecticide-treated orchards were done 7 or more days after the last insecticide application. Percent egg mortality was transformed (arcsin(sqrt(x + 0.5))) and subjected to analysis of variance (ANOVA) using month (June, August) as a repeated measure (Hintze 1987). If the 'month by treatment' interaction proved to be significant, a one-way ANOVA was used to compare treatments on each date. Fisher's LSD was used to separate significant treatment means. A paired $t$-test was used to compare the percentage of missing versus dead eggs among treatments on each date. Correlation statistics were calculated for the percentage dead and missing eggs both across and within treatments.

Tray samples were taken from a tree adjacent to each of the 10 assayed on the days when sleeves were attached and removed, and the mean of these two samples is reported. Branches were jarred sharply three times with a rubber club above a cloth screen (45 by 45 cm). Branches were hit less hard in August than in June because fruit loads were heavy in August. Predators were placed in vials containing 70% ethanol, then counted and sorted in the laboratory. Predators were grouped as heteropterans, earwigs (*Forficula auricularia* L.), and spiders. Heteropteran species included both anthocorids (*Orius tristicolor* (White), and *Anthocoris* spp.), mirids (*Deraeocoris brevis piceatus* (Knight) and *Campylomma verbasci* (Meyer)), and nabids (*Nabis* spp.). Predatory species such as ants, coccinellids, neuropterans, and a predatory red velvet mite, *Anystis* sp., were uncommon in our tray samples, and were therefore grouped as an additional category (other) included in the total predator density. A repeated measure ANOVA (by month) was used to compare densities of predators across treatments. When there was a significant date by treatment interaction, a one-way ANOVA compared treatments on each date. Fisher's LSD was used to separate significant means. Correlation statistics were used to compare the association of each predator group with the percentage of dead, missing, and dead + missing eggs for all orchards and within each treatment on both dates.

## RESULTS AND DISCUSSION

Mean levels of egg mortality within orchard types ranged from 10.1 to 37.0% during the season (Table 1). Levels in individual orchards ranged from 7.2 to 52.5% (Fig. 1). In June, total egg mortality did not differ among treatments ($F = 2.6$; df = 2,13; $p = 0.12$), but in August, egg mortality was highest in orchards not treated with insecticides, and was significantly higher in the 'MD plus insecticide' than in the 'conventional insecticide' orchards ($F = 15.1$; df = 2,13; $p < 0.001$).

**Table 1**

Mean percentages (SE) of egg predation in 1995 in apple orchards treated with organophosphate (OP) insecticides, mating disruption (MD) with limited use of OPs, or with MD alone.

| Month | % eggs dead | | | % eggs missing | | | % total egg mortality | | |
|---|---|---|---|---|---|---|---|---|---|
|  | OP | MD + OP | MD | OP | MD + OP | MD | OP | MD + OP | MD |
| June | 10.8 (1.8)a | 9.3 (1.0)a | 14.8 (0.9)a | 5.3 (1.5)a | 13.9 (2.7)b | 9.3 (2.9)b | 16.1 (2.8)a | 23.2 (2.3)a | 24.2 (3.5)a |
| August | 5.2 (1.5)a | 9.0 (1.4)a | 24.2 (3.1)b | 4.9 (1.4)a | 12.9 (4.5)b | 12.8 (3.1)b | 10.1 (1.7)a | 21.9 (4.7)b | 37.0 (6.2)c |

Means for % eggs dead, % eggs missing, and % total egg mortality across treatments for each month followed by a different letter are significantly different (Fishers LSD, $p < 0.05$).

There were no significant differences in the percentage of dead eggs among orchard types in June ($F$ = 2.0; df = 2, 13; $p$ = 0.17). However, the percentage of eggs categorized as dead was highest in the 'MD alone' treatment compared with the two insecticide treatments in August ($F$ = 13.8, df = 2,13, $p$ < 0.001). These were significant differences among treatments in the percentage of eggs missing ($F$ = 6.6; df = 2,13; $p$ = 0.01). More eggs were missing in the orchards treated with MD than in those treated with insecticide only. There was no significant difference in the percentage of missing eggs between treatments in the June and August samples ($F$ = 0.01; df = 1, 13; $p$ = 0.97) and no significant correlations between the percentage of eggs missing and the percentage of dead eggs within orchards ($p$ > 0.05). There were no significant differences in the mean percentages of the two types of egg mortality across all orchards or within each of the three orchard types, except for two cases. A significantly higher percentage of eggs was dead than missing in the insecticide-treated orchards in June ($t$ = 2.7; df = 7; $p$ = 0.03) and in August in the MD orchards ($t$ = 7.5; df = 3; $p$ < 0.01).

The mean number of predators was significantly different between orchard types ($F$ = 9.0, df = 2, 13, $p$ < 0.01) (Table 2). Predators were more numerous in the 'MD alone' orchards than in those treated with insecticides. There was no significant difference between the two types of insecticide-treated orchards and no significant difference in the density of predators between the June and August samples ($F$ = 0.6, df = 1, 13, $p$ = 0.46).

**Table 2**

Mean density (SE) of arthropod predators collected per 10 tray samples in 1995 from apple orchards treated with organophosphate (OP) insecticides, mating disruption (MD) with a limited use of OPs, and with MD alone.

| | OP insecticides | | | | | MD + OP insecticides | | | | | MD alone | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | H | E | Sp | O | T | H | E | Sp | O | T | H | E | Sp | O | T |
| June | 2.0a | 0.0a | 1.0a | 0.0a | 3.0a | 0.2a | 2.0a | 0.2a | 3.7b | 6.1a | 5.5a | 1.9a | 5.4b | 3.1b | 15.9b |
| | (0.6) | (0.0) | (0.4) | (0.0) | (0.8) | (0.2) | (1.0) | (0.2) | (2.0) | (2.0) | (1.2) | (1.4) | (1.8) | (1.0) | (2.7) |
| August | 0.7a | 0.3a | 0.7a | 0.1a | 1.8a | 4.1a | 0.0a | 3.8a | 0.1a | 8.0a | 7.2a | 2.0b | 10.0b | 0.7a | 19.9b |
| | (0.3) | (0.2) | (0.4) | (0.1) | (0.7) | (1.0) | (0.0) | (2.6) | (0.1) | (2.2) | (5.0) | (0.6) | (4.0) | (0.7) | (8.6) |

'H' = heteropterans; 'E' = earwigs; 'Sp' = spiders; 'O' = other (includes ants, red velvet mites, lacewing larvae and adults, and coccinellid larvae and adults); 'T' = total of all predators. Means for each predator group in each row followed by a different letter are significantly different, Fishers LSD, $p$ < 0.05.

The mean density of heteropteran predators in tray samples was not significantly different between treatments ($p$ = 0.06). The predominant heteropteran species were the two mirids, *D. brevis* and *C. verbasci*. Mirids were the major predators of codling moth eggs in Nova Scotia and England (MacLellan 1962, Glen 1975), however, levels of egg mortality were not correlated with their density. The population density of heteropteran predators is more often related to the densities of their major prey: phytophagous mites and aphids, the mix of surrounding vegetative habitats, orchard spray practices, and weather (MacLellan 1962, Glen 1977, Glen and Brain 1978, Thistlewood *et al.* 1990, Reding and Beers 1995, Horton *et al.* 1997). These factors can create large fluctuations in numbers of heteropterans between orchards and in different years (Horton *et al.* 1997). Recommendations to increase the density of predatory bugs in orchards have included providing alternative habitats in or near orchards, chemical attractants, and the use of selective insecticides (Horton *et al.* 1997). However, management of heteropteran egg predators in apple is seriously impaired by the feeding habits of *C. verbasci*. *Campylomma verbasci* overwinters in apple orchards and feeds early in the season on both arthropods and young developing fruits. An increasing number of apple orchards in Washington is being treated

for this pest, and its effective management relies on applications of OP or other broad spectrum insecticides at the prebloom or bloom stages (Reding and Beers 1995). Thus, while *C. verbasci* readily ate codling moth eggs in laboratory bioassays (A.L.K., unpublished data), its feeding habits limit its use as an egg predator.

Counts of earwigs in tray samples did not vary significantly between treatments in June ($p = 0.07$), but were significantly different in August ($F = 8.9$; df = 2,13; $p < 0.01$) (Table 2). Earwig density was significantly higher in the orchards treated only with MD compared with orchards treated with insecticides. Philips (1981) noted that earwigs are both pests and beneficial in apple orchards. Earwigs are reported to feed on aphids (Carroll and Hoyt 1984, Mueller *et al.* 1988); and studies in England (Glen 1975, 1977, Glen and Brain 1978) found that earwigs in cages readily eat codling moth eggs. Unfortunately, earwigs occasionally feed on fruits (J. Dunley, Wash. State Univ., personal communication), and this has limited both augmentative releases and conservation practices for this species in apple orchards.

Spiders were the most numerous predators in our samples, and their densities varied significantly between orchard types ($F = 8.4$; df = 2,13; $p < 0.01$) (Table 2). Spiders are good indicators of the ecological disturbance created by insecticide use in orchards (LeRoux 1960, Specht and Dondale 1960, Dondale *et al.* 1979, Madsen and Madsen 1982). In our study, spider densities were higher in orchards treated with MD than in those treated with insecticides. There was no difference between the June and August samples ($F = 3.0$; df = 1, 13; $p = 0.11$). Spiders are not likely to be a major predator of codling moth eggs, though there are a few reports of spiders feeding on lepidopteran eggs (Buschman *et al.* 1977, Jennings and Houseweart 1978). Spiders are more likely to prey on larvae. MacLellan (1973) found that spiders feeding on larvae helped to control populations of the tortricid leafroller, *Epiphyas postvittana*, in some apple orchards in Australia.

A number of other predators that may feed on codling moth eggs (Falcon and Huber 1991) were less common in our samples, such as mites (*Anystis* sp.) (1), ants (2), coccinellid larvae and adults (4), and lacewing larvae and adults (5). We found no predatory thrips. There were significantly more predators in the orchards treated with MD than with insecticides alone ($F = 5.9$; df = 2,13; $p = 0.01$), and significantly more in June than in August ($F = 5.0$; df = 1, 13; $p = 0.04$), perhaps because it was difficult to sample the mobile adult stages without dislodging fruit.

There were no significant correlations ($p > 0.05$) between any predator group or the total of all predators and egg mortality within each orchard type during either sampling period. However, across the 16 orchards, there were significant correlations between both the percentage of dead eggs and the percentage of dead plus missing eggs and the mean densities of earwigs, spiders, and total number of predators (r-values ranged from 0.51 - 0.59, *p's* < 0.05). The regression of total egg mortality (y) against the mean density of all predators (x) was described by the equation: y $= 14.2 + 0.7x$ ($R^2 = 0.32$, $p = 0.02$; Fig. 1).

These results show that the importance of predators in the biological control of codling moth has been overlooked in Washington apple orchards. Glen (1982), modeling predation of codling moth eggs in an unsprayed orchard in England, found that fruit injury would have been 6-fold higher in the absence of egg predators. Coupled with even higher levels of mortality of young larvae (MacLellan 1962, Westigard *et al.* 1976) by similar predators (Falcon and Huber 1991), predation in the absence of insecticides can reduce codling moth populations during the summer (MacLellan 1977, Ferro *et al.* 1975). However, natural mortality of codling moth eggs and young larvae is low in apple orchards where there is little diversity of predaceous species (Geier 1964, Wood 1965, Wearing 1979). In our study, using only OPs early in the season, reduced biological control of codling moth significantly (Table 1).

Integration of pest management tactics in apple as first proposed by Pickett (1959) and more recently termed 'second-stage' IPM (Prokopy *et al.* 1990) must rely on early season control of
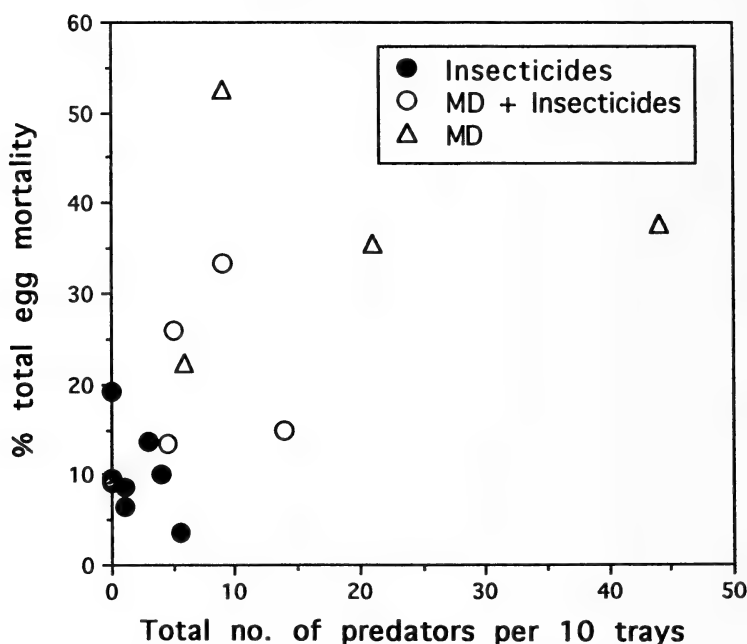
**Figure 1**. Percent total egg mortality (dead plus missing eggs) (y) plotted against mean density of all predators (x) per 10 beating-tray samples in August, 1995 for 16 apple orchards treated either with insecticides only, mating disruption (MD) for codling moth plus limited use of insecticides, or with MD alone.  y = 14.2 + 0.7x, $R^2$ = 0.32, p = 0.02.

pest populations with maximal use of behavioral, cultural, and biological control during the remainder of the season.  Mating disruption of codling moth is the keystone for this IPM program in western U.S. orchards.  However, studies of MD of codling moth in organic or unsprayed orchards have shown that this technique alone cannot reliably control codling moth (Pfeiffer *et al*. 1993, Trimble 1995, Judd *et al*. 1997).  In fact, current use of MD in conventional orchards reduces the number of orchards treated with OPs for codling moth by only 23% (Alway 1997).  We show that natural control of codling moth is reduced when OPs are used to supplement control of codling moth or to manage secondary pests.   Further reductions in the use of broad spectrum insecticides are needed to achieve the full potential of biological control.

Integration of ecological approaches and consideration of arthropod community structure may allow a new level of apple IPM (Gruys 1982, Liss *et al*. 1986, Kogan 1988).  Previous field studies in apple have found a significant decrease in the number and diversity of predators as human disturbance increases from unsprayed to organic to conventional orchards (LeRoux 1960, MacLellan 1972, Madsen and Madsen 1982, Brown and Aller 1989).  However, even if insecticides are used less, natural enemies in small, isolated MD orchards might not affect all codling moth populations (Knight 1995). Effective biological control of codling moth may require area-wide reductions in the use of broad spectrum insecticides and establishing specific cultural conservation practices within and surrounding orchards (Horton *et al*. 1997).

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# Mass-rearing and storing codling moth larvae in diapause: a novel approach to increase production for sterile insect release

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## ABSTRACT

A method that induces diapause, originally developed for individually reared codling moth (CM), *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), was tested on the open tray, sawdust-based diet system used in Canada for mass-rearing. The efficiency of the standard and diapause rearing systems are compared and the quality of the adults reared from the two systems is discussed. The benefits and economics of rearing and storing CM larvae in diapause are discussed and related to the ongoing CM eradication program.

**Key words:** *Cydia pomonella,* mass-rearing, diapause, insect quality, storing

## INTRODUCTION

The Sterile Insect Release (SIR) Program to eradicate the codling moth, *Cydia pomonella* (L.), in British Columbia began rearing and release operations in 1994 (Dyck *et al*. 1993). Its goal is to eradicate this key pest of apples and pears from the orchards of south-central BC by 2005 (OKSIRP Strategic Plan 1996). Infestations of codling moth (CM) were first reported at Victoria, BC, in 1900 and by 1916 it was a serious pest in the Okanagan and Similkameen Valleys, some 600 km away (Marshall 1951). At this latitude (49°), CM typically has two generations per year (Madsen and Vakenti 1973), with peak flight activity of overwintered adults in early May and in late July-early August for the summer generation (Madsen and Procter 1982).

During the 1960's and 70's, scientists with Agriculture Canada in BC, and USDA-ARS in the state of Washington, investigated SIR to eradicate CM (Proverbs 1971; Proverbs *et al*. 1969, 1982; White *et al*. 1976a, 1976b). In BC, Proverbs and colleagues developed an open tray, sawdust-based diet (Brinton *et al*. 1969) to mass-rear CM, which proved to be much more efficient and economical than conventional lepidopteran diets. The diet substitutes shredded paper pulp for agar as the binding agent, significantly reducing costs, and uses coarse sawdust to regulate moisture and provide shelters for developing larvae, thus reducing cannibalism and allowing more insect production per tray. Brinton *et al*. reported in 1969 that the new diet consistently produced about 200 adult CM per tray. We now use a modified version of the Brinton diet, with yields of about 1200 adults at a cost of about $3.00 Cdn per tray.

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CM production at the SIR facility is seasonal and follows the phenology of the wild population.  Moths (12-14 million per week in 1997) are reared from late March to mid-August and released into orchards at the rate of 2000/ha/week from May to September. In mid-August, rearing is cut back to a maintenance level of between 75000-100000 per week. Production for the next season is stepped-up in February, and peak production is reached in two generations (10-12 weeks).

The key to success with SIR is to produce and release so many competitive insects that the majority of matings in the field are with sterile moths.  A 40:1 sterile to wild ratio is necessary to suppress CM populations and eventually lead to eradication.   In the Okanagan and Similkameen Valleys the overwintering generation is the largest.  This, combined with cool rainy weather, makes it particularly difficult to achieve good overflooding ratios during peak spring adult flight in May.

Codling moths diapause as mature 5th-instar larvae (Brown 1991).  Diapause has been experimentally induced and successfully terminated in laboratory colonies, and has mostly been used to store larvae for post-harvest research (Singh and Ashby 1986; Ashby and Singh 1990).   If storage in diapause was used as a year-round insect production strategy for SIR, emerging moths would have to compete successfully with wild ones for the system to be useful.

Here, we examine laboratory-induced diapause as a tool to mass-rear and store CM for use in the current eradication effort in BC.   The efficiency of the diapause induction system, the timing of emergence from diapause and the quality of the diapaused adults are compared to moths from standard production and with some attributes of wild adults. The costs and benefits of the diapause rearing system are discussed.

## MATERIALS AND METHODS

*Rearing Comparisons.*  All rearing was done at the SIR CM mass-rearing facility in Osoyoos, BC, during the fall and winter of 1993.  Thirty trays (45x29x2.5 cm) of fresh diet were obtained from standard SIR production.  An egg sheet containing 2500-3000 CM eggs previously incubated at 27°C, 16L:8D, 70% RH for 2 days was placed on top of each tray.  Fifteen trays were placed in a rearing room under standard conditions (27°C, 16L:8D, 55% RH) for 21 days to serve as controls.  The other 15 trays were kept in a separate rearing room to induce diapause at 25°C, 12L:12D, 55% RH (Singh and Ashby 1986).   Egg sheets were removed after 7 days and percent hatch calculated.  Larval development in the diapause trays was compared with that in the controls once per week. The larvae normally pupate in the diet, beginning at about day 20.  However, during our first attempt to induce diapause in open trays, large numbers of mature larvae migrated out of the diet and wandered through the room.  In all subsequent rearing trials, 15-20 corrugated cardboard rolls (C- flute, 6 cm diam x 4 cm high) were placed vertically on top of each diet tray at day 18 to collect the wandering larvae.

At day 22, control trays (with late larvae or early pupae or both) were moved into an emergence room (27°C, 16L:8D, 30% RH), where adult eclosion began at day 30 and lasted about 2 weeks.  Adult moths were attracted to ultraviolet lights in the ceiling and transported through vacuum ducts to a cold room (0-2°C).  At day 45, 4 control trays were selected at random and pupal exuviae on the surface of the diet were counted on 1/4 of each tray.  The counts were summed and used as an estimate of adults produced per tray under standard conditions.

The cardboard rolls were removed from the trays on day 30.  The trays were then moved into an emergence room under long day conditions (27°C, 16L:8D, 30% RH) and

pupal exuviae were counted after 21 days as above. This number was used to estimate how many CM either did not enter diapause or entered diapause, spun cocoons in the diet and "broke" diapause when the trays were returned to long day conditions. The cardboard rolls containing diapausing larvae were placed in black polyethylene bags and room conditions adjusted to 15°C, OL:24D, 50% RH for 100 days (Ashby and Singh 1990). The bags were then moved to a cold room at 0-2°C, OL:24D, 50% RH, where they were stored for about 50 days (Ashby and Singh 1990). To terminate diapause, the rolls were placed in small emergence boxes at 27°C, 16L:8D, 30% RH (long day conditions). Date of first adult eclosion was noted and adult moths were collected and weighed daily until they had all emerged. The cardboard rolls were examined and total numbers of pupal exuviae, dead larvae and dead unemerged pupae were counted.

The experiment was replicated 5 times (30 trays per replicate, 15 control and 15 induced). The data from each replicate were first tested for homogeneity (means not significantly different at $p < 0.05$) and then pooled. The eclosion curve for adults emerging from diapause was plotted and compared with eclosion curves from standard rearing.

*Assessment of Moth Quality.* Sample moths from each replicate were collected and used to measure selected characters. Pupal and adult weights for both males and females, adult longevity (with water), female fecundity and fertility, and male mating ability were measured. For longevity, newly eclosed adults were placed individually in small plastic cups (29.5 ml) with a water-moistened cotton wick and kept at 25°C, 16L:8D, 50% RH. The cups were checked daily and the date of death recorded. For assessment of fecundity and fertility, individual newly eclosed females were paired with a virgin male from the colony in clear 200 ml plastic cups with lids; a wick through the lid provided moisture and was re-wetted daily. The pairs were allowed to mate and oviposit at 25°C, 16L:8D and 50% RH, until the female died. The cups were incubated at 25°C, 16L:8D and 50% RH for a further 7 days when the total eggs laid and number of hatched eggs were counted. To assess male mating ability, newly eclosed males were paired with virgin females from the colony in similar cups and allowed to mate for 48 hours. The males were paired with a new virgin female every 48 hours until death. The females were dissected and the total number of spermatophores produced by each male was determined. Data from each replicate were first tested for homogeneity (means not significantly different at $p < 0.05$) and then pooled. For comparison, a sample of cocooning larvae was assessed from corrugated cardboard bands placed around the trunks of 50 apple trees in Oliver, BC during July 1994. Statistical differences between means of laboratory data were compared by examining the 95% confidence limits around each value (Jones 1984).

*Cost Comparisons.* A comparison was made of the costs associated with rearing CM under standard and diapause conditions. The calculations took into account the cost of diet and all materials employed in rearing. The costs of electrical power and gas consumption, facility wear-and-tear, and labour associated with both rearing processes were estimated. Finally, the efficiency of each rearing system, *i.e.*, the number of adults produced, was included.

## RESULTS AND DISCUSSION

In 1993, about 850 adults were reared per tray under standard conditions, which represents about 39% of the neonates that hatched (72.2% egg hatch and 3000 eggs/sheet). In 1997, standard production has increased to 1270 adults per tray and

percent hatch is currently 81%. Rearing efficiency (hatched egg to adult) has therefore increased to 52.3%, mainly because of better process control during mass-rearing.

Our current artificial diet loses moisture over the 3-4 week larval rearing period at 27°C, 16L:8D, 55% RH. When 5th-instar larvae are ready to spin cocoons and pupate, the diet provides a suitable dry site in which to do so. Most larvae reared under these conditions pupate inside their individual feeding tubes and eclose directly from the diet. Larval wandering, although normal in both generations in the wild (Madsen and Procter 1982), has largely been eliminated in the modified Brinton diet system. We expected that larvae induced into diapause would behave similarly and spin overwintering hibernacula inside the diet. A large number of mature diapausing larvae wandered out of the diet before spinning hibernacula. We captured most of the larvae in corrugated cardboard rolls placed on the diet at day 18 before they started to wander. Collecting the larvae into this inert cocooning material unexpectedly reduced the risk of pathogen infection and allowed for cleaner storage of the diapausing larvae.

A comparison of the efficiency of standard and diapause rearing methods is given in Table 1. In 1993, the mean number of adults per tray using standard rearing was 813. When rearing through diapause, the mean number of adults per tray recovered from the rolls after conditioning and chilling was 584. An additional 125 adult moths eclosed directly from the diet when it was returned to long day conditions. Diapause rearing was only 87.2% as efficient as the standard rearing system (584 + 125 vs. 813).

**Table 1**

A comparison of standard and diapause rearing methods for codling moths.

| Stage | % of Individuals per tray of diet (Mean±SD) | |
|---|---|---|
| | Standard | Diapause |
| Egg hatch | 77.2 (1923±205) | 77.5 (2106±257) |
| Adults from non-diapausing larvae | 100.0 (813±185) | 15.2 (125±47)[a] |
| Larvae diapausing | 0.0 | 84.8 (688±157) |
| Dead 5th-instar larvae/pupae | 1.4 (9±4) | 1.7 (10±4) |
| Adults from diapausing larvae | 0.0 | 72.8 (584±80) |
| Larvae not accounted for | - | 12.5 (94±9) |

[a] Number that eclosed from larvae that did not diapause or that diapaused in the diet.

The 125 adults that eclosed directly from the diet came from larvae that either failed to diapause under our conditions or were induced into diapause but failed to wander and cocooned inside the diet. Ashby and Singh (1990) found that when larvae from a New Zealand colony were moved to long day conditions immediately after diapause was induced only 57.7% were able to eclose over 1 year. However, Peterson and Hamner (1968) reported that 97% of CM broke diapause after 28 days in long day conditions immediately after it was induced. We thoroughly examined the diet after 21 days in long day conditions and found no unemerged CM. Our colony responded similarly to that of Peterson and Hamner (1968). The SIR Program prepares 1-2 diet batches per week to maintain a stock colony of between 75000-100000 CM during the fall and winter. Because there is approximately a 10-fold increase per generation, only 10% of the adults produced per batch are used for breeding and 90% are discarded (during the release season, 10% of adults are kept for breeding and 90% are sterilized and released into the field). If diapause rearing were implemented at the SIR facility in fall and winter, the larvae collected in the cardboard rolls could be stored and the CM remaining in the diet

could be made to emerge under long day conditions and used as the stock colony, thereby eliminating any production waste.

With the diapause method, 94 of the 688 larvae per tray that entered diapause and wandered were lost. They probably spun hibernacula directly on the tray carts or room walls. Future research will focus on improving both the capture of wandering larvae and the response of colony CM to diapause induction cues.

The emergence curve for diapaused adults was remarkably similar to that from standard rearing, where adults begin to eclose from the diet around day 30, peak emergence occurs around day 35 and the diet is discarded after day 42. Diapaused adults began emerging 16 days after placement under long day conditions, peak emergence occurred on days 19-20, and by day 24 more than 95% of the adults had eclosed.

Comparisons of CM reared by standard and diapause methods and for wild CM are summarized in Table 2. Mean pupal weight of diapaused males was significantly higher than for males from standard colony or wild material. We cannot explain this significant difference. Typically, overwintered wild CM are lighter than those from the summer generation (Riedl 1983); however, this was not the case when colony adults were reared through diapause. The weights of female pupae or adults (male or female) were not significantly different.

## Table 2

A comparison of various quality characters of codling moths reared by standard and diapause methods and collected in the wild (n=number of individuals measured).

| Quality character | Rearing method | | |
|---|---|---|---|
| (Mean ± 95% CI) | Standard | Diapause | Wild |
| Pupal weight (mg) | | | |
| males | 30.93±1.15 | 36.66±0.79 | 31.09±0.77 |
| (n) | (50) | (125) | (50) |
| females | 39.22±1.68 | 40.59±2.09 | 40.47±1.26 |
| (n) | (50) | (125) | (50) |
| Adult weight (mg) | | | |
| males | 19.72±0.94 | 19.14±0.57 | 18.86±0.69 |
| (n) | (50) | (125) | (50) |
| females | 29.75±1.43 | 29.97±0.78 | 30.90±1.10 |
| (n) | (50) | (125) | (50) |
| Longevity (days) | | | |
| males | 14.36±0.69 | 11.54±0.77 | 10.32±1.61 |
| (n) | (50) | (118) | (50) |
| females | 11.22±0.66 | 10.71±0.60 | 9.34±1.22 |
| (n) | (50) | (119) | (50) |
| Eggs per female | 216.28±17.60 | 181.74±14.48 | -- |
| (n) | (50) | (50) | |
| % Egg hatch | 88.90±3.28 | 84.15±3.27 | -- |
| Spermatophores | | | |
| per male | 4.70±1.10 | 4.51±1.25 | -- |
| (n) | (25) | (25) | |

Tauber *et al.* (1986) suggested that some developmental, reproductive or survival costs and benefits are associated with a physiological trait like diapause, and that for some species the reproductive costs may be direct, *e. g.*, reduced fecundity. In our experiments the fecundity of diapaused females was significantly lower ($p < 0.05$) than for standard

females, although the proportion of eggs that hatched was similar for both groups. We found males significantly ($p < 0.05$) longer lived from standard than from diapause or wild rearing. Females from standard rearing also lived longer, although the difference from the other groups was not significant. Induction into diapause requires that larvae use some resources while in hibernation (6-9 months) and this may influence adult longevity. The wild CM were also shorter lived than the standard colony insects, perhaps because they die sooner from the stress of being handled. Wild females also did not mate or oviposit in the laboratory. No significant difference was found in mating ability between diapaused and standard males as determined by the mean number of spermatophores produced. In general, moths reared through diapause and stored for 6 months appear to be similar in quality to those reared under standard conditions.

Costs associated with mass-rearing CM with standard and diapause methods are compared in Table 3. The higher cost of diapause rearing is due to the cardboard rolls ($0.05/roll 20 rolls/tray) and the cost of labour to place and remove them. When the efficiency of diapause rearing (87.2%) is factored in, the cost of producing 1000 adults increases from $3.69 to $6.06. Although the cost of rearing through diapause is higher than the standard method, this is partly offset by efficiencies associated with continuous production and the added security of having several million CM in storage.

**Table 3**

A comparison of costs between standard and diapause rearing methods in 1993.

| Rearing method | Cost per diet tray ($Cdn) | Mean adults per tray | Cost per 1000 adults ($Cdn) |
|---|---|---|---|
| Standard | 3.00[a] | 813 | 3.69 |
| Diapause | 4.30[a,b] | 709[c] | 6.06 |

[a] Includes cost of diet ingredients, labour, and facility operation.
[b] Includes cost of cardboard rolls to collect wandering diapausing larvae, labour to place and remove cardboard rolls, and cold storage.
[c] Includes number of diapaused adults eclosed from cardboard rolls on a tray plus the number that eclosed from the diet in that tray.

We show that diapause induction, originally developed for individually reared CM, can be applied to the mass-rearing system used by the SIR eradication program in BC. The technique may increase the program's efficiency by allowing year-round insect production, and could provide additional sterile CM for use in emergencies and even for export.

# ACKNOWLEDGEMENTS

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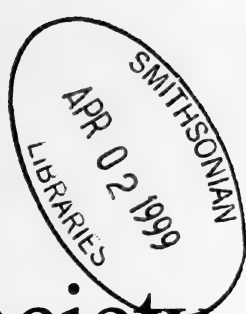# Entomological Society
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ESBC

*COVER*: An adult male Variable Darner (*Aeshna interrupta*) emerging on a Marsh Cinquefoil (*Potentilla palustris*) plant. The cast skin of the final-instar larva remains clinging to the plant above the dragonfly.

The Variable Darner is one of the most common dragonflies in the rangeland ponds of the drier plateaus and valleys of southern British Columbia. All over the province, it lives in sedgy ponds or lakes and, especially along the coast, around bog and fen pools. The common name comes from the shape of the lateral thoracic stripes of the male, which are usually very thin. These stripes are complete in most specimens from the Interior of the province, but are divided into spots (thus, *interrupta*) in coastal ones. The specimen was drawn by Rob Cannings.

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# Effects of cold storage on adult emergence and fecundity of *Choristoneura occidentalis* (Lepidoptera: Tortricidae)

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## ABSTRACT

The effects of cold storage on *Choristoneura occidentalis* Freeman pupae, in darkness at $2.0 \pm 0.5$ $^{0}$C and 100% R.H. for 0 to 10 weeks, were determined on adult emergence, adult longevity, the number of eggs laid per female, and egg viability in the laboratory. The proportion of adults emerging was not significantly reduced after pupae were stored in the cold room for up to 2 weeks. No adults emerged from pupae being stored for 8 weeks or longer. The lifespan of adult females was longer than that of males. The differences in adult longevity between the two sexes increased after pupae were exposed to cold storage. Cold storage of *C. occidentalis* pupae significantly reduced adult longevity: longer pupal storage resulted in a shorter adult lifespan. After 1 week of cold storage of the pupae, the mean number of eggs laid per female and egg viability were not significantly reduced as compared with those for females not exposed to cold storage as pupae. Egg production and egg viability, however, were significantly reduced when pupae were subjected to cold storage for 2 weeks or longer. Considering all the parameters measured, pupae may be exposed to cold storage for 1 week without deterioration in adult quality.

**Key words:** *Choristoneura occidentalis*, cold storage, adult longevity, fecundity.

## INTRODUCTION

Larvae of the western spruce budworm, *Choristoneura occidentalis* Freeman, undergo obligatory diapause and overwinter in the second larval stage in nature. After about 8 months in diapause, larvae resume development the following spring (Shepherd *et al.* 1995). A non-diapausing colony of *C. occidentalis* was induced in the laboratory, and has been successfully reared on artificial diet since early 1970 (Lyon *et al.* 1972). Compared to a diapausing colony, the non-diapausing colony has a shorter generation time, permitting more rapid adjustments in colony size. This advantage facilitates mass rearing, providing a convenient source of experimental insects for research. Although it is relatively easy to rear *C. occidentalis* on artificial diet in the laboratory, it is time-consuming. Sometimes it is difficult to maintain a large colony to ensure a continuous and qualitatively uniform supply of insects. But there are times when more insects may be produced than can be used immediately. It would be desirable to use these extra insects later if they could be cold stored for a time, without deterioration in their quality.

Cold storage has been used in biological control programs to hold beneficial insects temporarily in the laboratory, to synchronize releases with the development of pest insects in the field, to accumulate sufficient numbers of beneficial insects for field release, or to balance supply and demand in the market (Gilkeson 1990; Bueno and Van-Cleve 1997). Cold storage is also used as a quarantine treatment for some species of insects (Yokoyama and Miller 1989; Toba and Moffitt 1991), and to hold insect cultures temporarily for future research without maintaining continuous rearings. Previous research has shown that cold storage of insects at low temperatures, ranging from 0 $^{0}$C to 10 $^{0}$C, negatively affects their quality, but to

date, no studies have documented the effects of cold storage on survivorship and fecundity in *C. occidentalis*.

The current study was conducted to determine the effects of cold storage of *C. occidentalis* pupae on adult emergence, adult longevity, the number of eggs laid per female, and egg viability.

# MATERIALS AND METHODS

**Insects.** Pupae used in this study were obtained from a non-diapausing laboratory colony of *C. occidentalis*, which had been reared on artificial diet since 1982. Larvae were reared in groups of five in 20-ml creamer cups on artificial diet modified after Robertson (1979) without formalin, at $20 \pm 1$ °C and 55-60% R.H., with a photoperiod of 16:8 (L:D) h. Larvae pupated in the cups and the pupae were collected daily. After collection, the pupae were placed in Petri dishes under the above rearing conditions for 48 h. They were then sexed and 10 male or 10 female pupae were placed in a 170-ml fluted food cup (Sweetheart Cup Co. Inc., Chicago, IL). A total of 550 pupae were thus prepared in 55 cups for each sex. The cups containing 10 pupae each of either males or females were randomly divided into 11 groups. Each group consisted of 10 cups, 5 for each sex. Each cup containing either 10 male or 10 female pupae was used as a replicate. Thus, there were five replicates for each sex in each group. Twenty pupae of each sex in two cups were randomly selected from each group and weighed to the nearest 0.1 mg, using a Sartorius analytical balance.

**Effects of Cold Storage on Adult Emergence and Longevity.** All pupae were 3 days old before they were stored in darkness at $2.0 \pm 0.5$ °C and 100% R.H. for either 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 weeks. For 0 week, the pupae were not cold stored. Following the cold treatment, the pupae were moved to conditions of $20 \pm 1$ °C and 55-60% R.H., with a photoperiod of 16:8 (L:D) h. The pupae were checked twice a day for adult emergence. The proportion of males and females emerging was recorded for each replicate. The data were normalized by arcsine-square root transformation, and the transformed data were subjected to a repeated measures analysis of variance to analyze the effects of sex and cold storage duration on adult emergence, using SYSTAT (SPSS Inc. 1996).

To determine the effects of cold storage on adult longevity, freshly emerged adults from each group (50 pupae of each sex) in the above described emergence observation were paired. One pair of adults was placed in a 170-ml cup at $20 \pm 1$ °C and 55-60% R.H., with a photoperiod of 16:8 (L:D) h. Up to 20 pairs of adults from each group were set up this way, depending on the number of adults that emerged in a group. Adults were observed twice a day until they died. The longevity data were transformed as $\sqrt{(x + 0.5)}$, where x is longevity in days. The transformed data were subjected to a repeated measures analysis of variance to analyze the effects of sex and cold storage on adult longevity.

**Effects of Cold Storage on Adult Fecundity.** Female adults used in the longevity observation from each group laid their eggs in the 170-ml cups. The eggs were maintained at $20 \pm 1$ °C and 55-60% R.H., with a photoperiod of 16:8 (L:D) h. When the eggs started hatching, the larvae were counted and removed from the cups daily. Unhatched eggs were counted with the aid of a dissecting microscope at 5X magnification. Numbers of hatched and unhatched eggs were recorded for each female. Egg viability was assessed as the percentage of eggs hatching. The data on the total number of eggs laid by a female were transformed as $\sqrt{(x + 0.5)}$, where x is the number of eggs, whereas the data on egg hatching percentage were normalized by arcsine-square root transformation. The transformed data were subjected to a repeated measures analysis of variance to analyze the effects of cold storage on mean number of eggs laid per female and on percentage of egg hatching.

# RESULTS

On average, female pupae of *C. occidentalis* weighed 98.6 ± 1.3 mg (± SE, *n* = 220) with a maximum of 140.4 mg and a minimum of 51.5 mg, and males weighed 66.0 ± 0.9 mg (*n* = 220) with a maximum of 105.3 mg and a minimum of 26.3 mg. Differences in pupal weight between the two sexes were significant ($F$ = 463.6; df = 1,438; $P$ = 0.0001). There were no significant differences in the pupal weight among the groups of males ($F$ = 1.0; df = 10,209; $P$ = 0.4543), or among the groups of females ($F$ = 1.1; df = 10,209; $P$ = 0.3991), suggesting that group weights, within sex, were equivalent before cold storage.

**Effects of Cold Storage on Adult Emergence and Longevity.** The proportion of adults emerging was significantly reduced by cold storage ($F$ = 104.3; df = 7,56; $P$ = 0.0001), and was not significantly different between males and females ($F$ = 0.1; df = 1,8; $P$ = 0.7890) (Fig. 1). The percentages of adults emerging (pooled males and females) were 97.0%, 98.0%, and 92.0% after pupae were stored for 0, 1, and 2 weeks, respectively. No significant differences ($P$ > 0.05) in these emergence rates were found. However, after 3 weeks cold storage of pupae, adult emergence was significantly ($P$ < 0.05) reduced. Although adults still emerged after 5 weeks cold storage of pupae, 100% of them were malformed. These malformed adults did not mate, and the females did not lay any eggs (see results below). After 8 weeks cold storage of pupae, no adults emerged (Fig. 1).
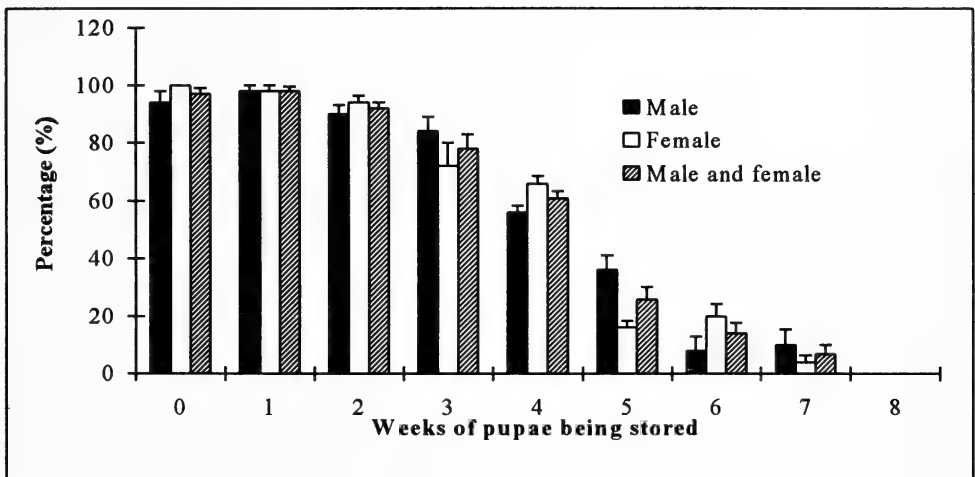


**Figure 1.** Relationship between cold storage of pupae and adult emergence of *Choristoneura occidentalis*. Vertical bars represent standard errors of mean adult emergence percentage, *n* (replicate) = 5. Where there are no vertical bars, the emergence from each replicate was the same.

Adult females had significantly longer ($F$ = 14.0; df = 1,4; $P$ = 0.02) lifespans than males, and differences in longevity between the two sexes increased with the length of storage ($F$ = 3.35; df = 7,28; $P$ = 0.03). Longevity of both male and female adults was significantly reduced by cold storage of the pupae ($F$ = 13.1; df = 7,28; $P$ = 0.0001) (Fig. 2).

**Effects of Cold Storage on Adult Fecundity.** The mean number of eggs laid per female was significantly reduced by cold storage of the pupae ($F$ = 42.0; df = 4,76; $P$ = 0.0001) (Fig. 3 A). The differences in mean numbers of eggs per female between 0 and 1 week cold storage of pupae were not significant ($P$ > 0.05), but egg production was significantly reduced when pupae were stored for longer than 1 week ($P$ < 0.05).
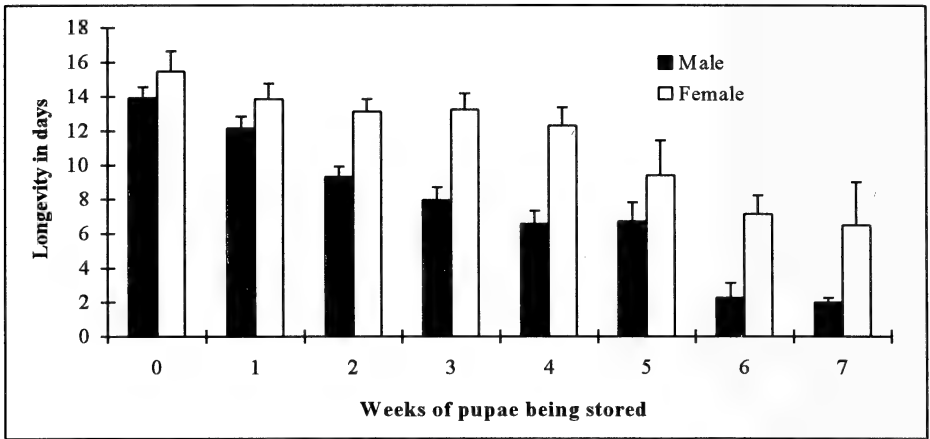
**Figure 2.** Relationship between cold storage and adult longevity of *Choristoneura occidentalis*. Vertical bars represent standard errors of mean longevity, *n* (replicate) = up to 20, depending on the number of adults emerged in each group.
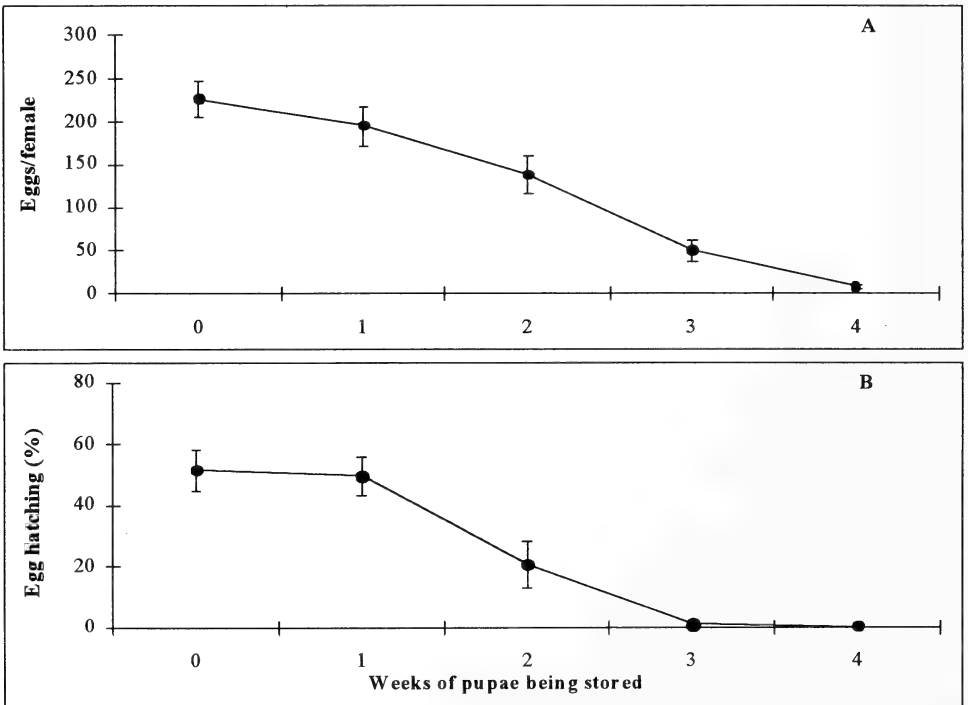


**Figure 3.** Relationship between cold storage of pupae and the number of eggs laid per female of *Choristoneura occidentalis* (A), and egg viability (B). Vertical bars represent standard errors of mean, *n* (replicate) = up to 20, depending on the number of females that laid eggs in each group. Where there are no vertical bars, mean value from each replicate was the same.

Egg hatching was adversely affected by cold storage of the pupae ($F = 15.4$; df = 3,48; $P = 0.0001$) (Fig. 3 B). Although percentage of egg hatching after 1 week cold storage of the pupae was lower than that for 0 week storage, the difference was not significant ($P > 0.05$). Egg viability was dramatically ($P < 0.05$) reduced after 2 weeks cold storage of the pupae. When pupae were stored for 3 weeks or longer, almost no eggs hatched.

## DISCUSSION

Egg hatching rate in this study was only about 50%, for the control pupae that had not received cold storage treatment. The long period of laboratory rearing ($> 100$ generations) might have caused a deterioration in percentage of egg hatching. Lyon *et al.* (1972) noticed that egg viability of non-diapausing *C. occidentalis* dropped from 88% in the 6th generation to 59% in the 17th generation.

Differences in longevity between adult males and females increased after pupae were subjected to cold storage. The longer the pupae were stored, the greater the differences became. These results indicated that female pupae may have been more tolerant to cold storage than males. We do not know what constituents of female pupae are responsible for the cold tolerance.

The results clearly indicated that cold storage of *C. occidentalis* pupae adversely affected the proportion of adults emerging, adult longevity, mean number of eggs laid per female, and egg viability. After 1 week cold storage of the pupae, all parameters measured were not significantly different from those for 0 week storage. Cold storage of pupae for 2 weeks did not significantly affect adult emergence, but did reduce adult longevity, mean number of eggs laid per female, and egg hatching rate. We conclude that non-diapausing *C. occidentalis* pupae may be stored in darkness at $2.0 \pm 0.5$ °C and 100% R.H. for 1 week without deterioration in adult quality.

## ACKNOWLEDGEMENTS

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# Green leaf volatiles disrupt and enhance response by the ambrosia beetle, *Gnathotrichus retusus* (Coleoptera: Scolytidae) to pheromone-baited traps

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## ABSTRACT

Experiments were conducted to test the null hypothesis that green leaf volatiles, abundant in herbaceous plants and angiosperm trees, have no effect on the response by the conifer-infesting ambrosia beetle, *Gnathotrichus retusus* (LeConte), to pheromone-baited traps. A blend of four green leaf alcohols, 1-hexanol, (*E*)-2-hexen-1-ol, (*Z*)-2-hexen-1-ol, and (*Z*)-3-hexen-1-ol, each released at ca. 4 mg per 24 h, combined with a blend of two green leaf aldehydes, hexanal and (*E*)-2-hexenal, each released at ca. 13.0 mg per 24 h, reduced catches of females to levels not significantly different from those in unbaited control traps. Any of the four green leaf alcohols released alone disrupted responses of females, while 1-hexanol and (*E*)-2-hexen-1-ol strongly reduced catches of males. The two green leaf aldehydes released together, and (*E*)-2-hexenal released alone, weakly enhanced trap catches. These results lead to rejection of the null hypothesis on the basis of both positive and negative effects. Disruptive green leaf volatiles may have promise as forest product protectants against ambrosia beetles, by disguising hosts as non-hosts.

## INTRODUCTION

*Gnathotrichus retusus* (LeConte) is one of three economically important ambrosia beetles in western Canada and the USA (Borden and McLean 1981). Together with *G. sulcatus* (LeConte) and the striped ambrosia beetle, *Trypodendron lineatum* (Olivier), *G. retusus* attacks green coniferous timber in the woods and in processing areas (Prebble and Graham 1957; Johnson 1958). The annual economic impact on the British Columbia (BC) coast was estimated by McLean (1985) to be $63 million (Can.), but this has since been updated to range from $95 to $189 million (Lindgren and Fraser 1994).

In timber processing areas in BC, ambrosia beetles have been the target of an integrated pest management (IPM) program since the early 1980's (Borden 1995). The primary components of the program are management of log inventories so as to minimize exposure of vulnerable logs to attack, and interception of host-seeking beetles by mass trapping them in semiochemical-baited traps. For *G. retusus* the attractive semiochemical baits are the aggregation pheromone (*S*)-(+)-6-methyl-5-hepten-2-ol (retusol) and the host tree kairomones ethanol and α-pinene (Borden *et al.* 1980a,b).

As effective as the IPM program is, the need remains for an efficient, cost-effective material that could be used to protect logs from attack. Such a material would disrupt response of beetles in some way to attractive pheromones and kairomones, e.g. through arresting or repelling them prior to their reaching the attractive source (Borden 1997). A

disruptant tactic would complement current management practices. Two potential repellents have been rigorously evaluated. Pine oil and oleic acid protected logs from attack by *G. sulcatus* and *T. lineatum* for 49.5 and 41.2 days, respectively (Nijholt 1980). However, both materials are relatively expensive, and pine oil is particularly unpleasant and difficult to work with. Another possible source of repellency is non-host volatiles such as green leaf volatiles (GLVs), six-carbon alcohols, aldehydes and derivative esters common to a wide variety of angiosperm trees and shrubs (Visser and Ave 1978; Visser 1986). GLVs have been demonstrated to have varying degrees of repellency to nine species of scolytid beetles (Dickens *et al.* 1992; Wilson *et al.* 1996; Borden *et al.* 1997; Savoie *et al.* 1998; Deglow and Borden 1998; Poland *et al.* 1998).

Borden *et al.* (1997) reported that, for *T. lineatum* in the BC interior, four green leaf alcohols [1-hexanol, (*E*)-2-hexen-1-ol, (*Z*)-2-hexen-1-ol, and (*Z*)-3-hexen-1-ol] released alone or in a quaternary blend resulted in a 63% to 78% reduction of catches in traps baited with the aggregation pheromone, lineatin. In one of two experiments on the BC coast, the quaternary blend was weakly inhibitory. No inhibitory effect was found for the aldehydes, hexanal and (*E*)-2-hexenal, but in one of two experiments in the interior the binary blend caused a moderate enhancement of catches in lineatin-baited traps. Against *G. sulcatus*, only (*E*)-2-hexen-1-ol caused a significant reduction of catches in traps baited with the aggregation pheromone sulcatol (Deglow and Borden 1998). However, binary, ternary and quarternary blends of the above alcohols were all effective and caused disruption in an additive and redundant manner. Conversely (*E*)-2-hexenal alone and with hexanal weakly enhanced attraction.

Our objective was to test the null hypothesis that non-host GLVs (both aldehydes and alcohols) would have no effect on the aggregative response of *G. retusus* to its pheromone retusol.

## MATERIALS AND METHODS

Experiments on *G. retusus* were set up in an abandoned dryland log sort at an elevation of 500 m, at North Bend, BC in the Interior Douglas-fir (IDF) biogeoclimatic zone (Hope *et al.* 1991). The forest is dominated by Douglas-fir, *Psuedotsuga menziesii* (Mirb.) Franco, with some black cottonwoods, *Populus trichocarpa* Torr. & Gray, paper birches, *Betula papyrifera* Marsh, and mixed deciduous brush near the edge. The sort was largely empty, except for some Douglas-fir and western red cedar logs, *Thuja plicata* Donn ex D. Don, stacked in the central area, and scattered piles of coarse woody debris. Twelve-unit multiple funnel traps (Lindgren 1983) were hung from ropes or poles, at least 15 m apart, and away from deciduous trees, around the perimeter of the dryland sort.

Three randomized complete block experiments (Exp.) were conducted, with dates and numbers of replicates as in Table 1, and chemical stimuli, sources, purities, release devices and release rates as in Table 2. In each experiment, pheromone-baited and unbaited control traps served as positive and negative control treatments, respectively, against which the bioactivity of GLV treatments added to retusol could be assessed. Exp. 1 tested an aldehyde blend, hexanal and (*E*)-2-hexenal, and an alcohol blend, 1-hexanol, (*E*)-2-hexen-1-ol, (*Z*)-2-hexen-1-ol, and (*Z*)-3-hexen-1-ol, alone and together. Exp. 2 tested the two aldehydes alone and together, and Exp. 3 tested the four alcohols alone and in a quaternary blend. Captured insects were stored frozen in plastic bags prior to sexing and counting.

**Table 1**

Numbers, dates, and numbers of replicates for field trapping experiments on *G. retusus* at North Bend, BC.

| Exp. No. | Dates | Number of replicates[a] |
|---|---|---|
| 1 | 8 May-4 June, 1996 | ♂5, ♀ 8 |
|  | 24-29 June, 1996 | ♂ 7, ♀ 7 |
|  | 29 June-6 July, 1996 | ♂2, ♀ 2 |
| 2 | 4-12 June, 1996 | ♂5, ♀ 7 |
|  | 6-13 July, 1996 | ♂ 8, ♀ 10 |
| 3 | 13 July-30 Aug., 1996 | ♂6, ♀ 10 |

[a]Exp. 1-3 had 5, 5 and 7 treatments, respectively. A replicate represents all of the beetles captured in one randomized block of traps. In Exp. 1 and 2 treatments were re-randomized to produce new replicates on different dates. When no beetles of a given sex were captured in any trap within a replicate, that replicate was discarded, causing uneven numbers of replicates between sexes.

**Table 2**

Description of semiochemicals used in trapping experiments for the effect of GLVs on *G. retusus*.

| Chemical[a] | Source[b] | Purity(%)[b] | Experiments | Release rate (mg per 24 h)[c] |
|---|---|---|---|---|
| retusol | P | 100 | 1-3 | 5.0-6.0 |
| hexanal | A | 98 | 1, 2 | 13.0 |
| (*E*)-2-hexenal | A | 99 | 1, 2 | 13.0 |
| 1-hexanol | A | 98 | 1, 3 | 3.8 |
| (*E*)-2-hexen-1-ol | A | 95 | 1, 3 | 3.8 |
| (*Z*)-2-hexen-1-ol | B | 92 | 1, 3 | 3.8 |
| (*Z*)-3-hexen-1-ol | A | 98 | 1, 3 | 3.8 |

[a]All GLVs stabilized with 1-2% (wet weight) Ethanox® 330 antioxidant, Ethyl Chemicals Group, Baton Rouge, LA
[b]P=Phero Tech Inc., Delta, BC; A=Aldrich Chemical Company, Milwaukee, WI; B=Bedoukian Research Inc., Danbury, CT. Purities as determined by manufacturer.
[c]All chemicals released from bubble caps (Phero Tech Inc.) at rates determined by Phero Tech in the laboratory at 22-24°C.

To satisfy criteria for normality and homoscedasticity, all data (except Exp. 1, males) were transformed by log(x+1) (Zar 1996). Means catches were compared by ANOVA (GLM procedure, SAS institute Inc. 1988) and the Ryan-Einot-Gabriel-Welsh Multiple Q-test (REGW test) (SAS Institute Inc. 1988; Day and Quinn 1989). For male *G. retusus* in Exp. 1, Friedman's nonparametric randomized block analysis of variance (Zar 1996) was used, as the data were non-normal and heteroscedastic. Values for missing data (four in Exp. 1 and two in Exp. 2) were estimated using Li's (1964) procedure (Zar 1996). In all cases $\alpha=0.05$.
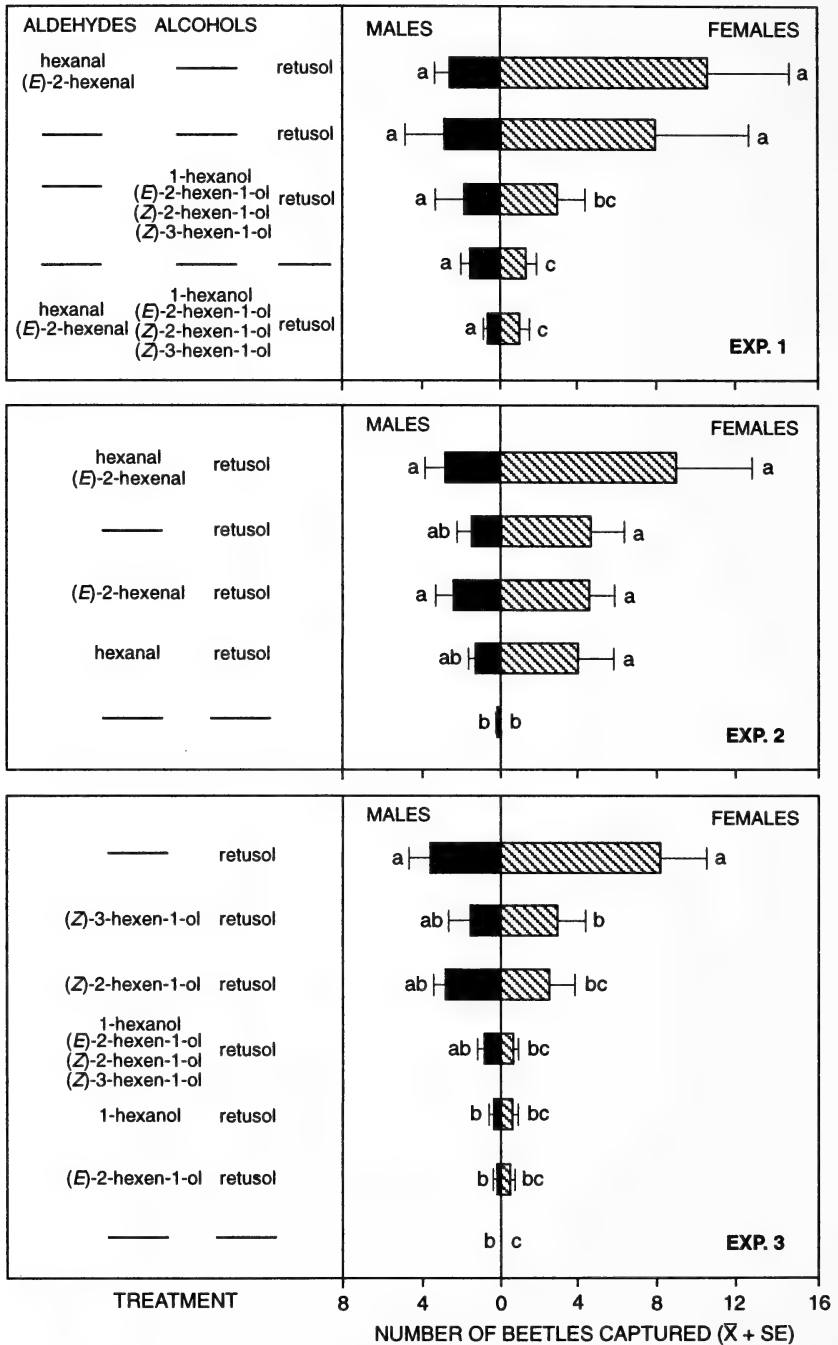
**Figure 1.** Captures (in rank order for females) in Exp. 1-3 of *G. retusus* to multiple-funnel traps baited with retusol alone or with a blend of two green leaf aldehydes and four alcohols (Exp. 1), the aldehydes alone and together (Exp. 2), and the alcohols alone and together (Exp. 3). Long dash indicates no treatment. In Exp. 1, bars for females with the same letter are not significantly different, REGW test, $P<0.05$, n=17; for males Friedman's nonparametric randomized block analysis of variance failed to detect significant differences, $P>0.05$, n=14. In Exp. 2 and 3, bars with the same letter are not significantly different, REGW test, $P<0.05$. For males and females in Exp. 2 and 3, respectively, n=13 and 17, and 6 and 10.

# RESULTS

In Exp. 1, the aldehyde-alcohol blend reduced catches of female *G. retusus* in retusol-baited traps to levels not significantly different from those in unbaited control traps (Fig. 1). Males did not discriminate at all between treatments. In Exp. 2, males responded at levels significantly greater than to unbaited control traps when retusol was combined with the aldehyde blend or (*E*)-2-hexenal (Fig. 1). Females did not discriminate between retusol alone or with either or both green leaf aldehydes. In Exp. 3, both 1-hexanol and (*E*)-2-hexen-1-ol reduced responses by males to levels significantly lower than to retusol, and not different from those to unbaited control traps (Fig. 1). For females, all alcohol treatments caused catches to be significantly lower than to retusol alone, and all but (*Z*)-3-hexen-1-ol reduced catches to levels that could not be discriminated from those in unbaited control traps.

# DISCUSSION

Our results demonstrate that green leaf volatiles can both enhance and disrupt the response of *G. retusus* to its aggregation pheromone. Therefore, the null hypothesis is rejected on the basis of both positive and negative effects. A similar disruptive effect was achieved with various GLVs on other conifer-inhabiting scolytids (Deglow and Borden 1998). However, enhancement of response to aggregation pheromones by GLVs is known to occur only in response to aldehydes by the ambrosia beetles *G. sulcatus* (Deglow and Borden 1998) and *T. lineatum* (Borden *et al.* 1997), and to 1-hexanol, a multifunctional pheromone for the bark beetle *Pityogenes knechteli* Swaine (Savoie *et al.* 1997). The weak attractive effect of hexanal and the aldehyde blend for *G. retusus* in Exp. 2 was overridden by the disruptive effect of the alcohols when the aldehyde and alcohol blends were combined in Exp. 1.

The powerful disruptive effect of the alcohols on females most likely reflects their strong response to pheromone in the absence of the alcohols. However, despite the moderate response by males to retusol, the disruptive effect of 1-hexanol and (*E*)-(2)-hexen-1-ol in Exp. 3 was still evident. It would be highly adaptive for pioneer male *G. retusus* to use any olfactory signal that would allow them to discriminate between potential hosts and non-hosts, thereby avoiding the risks of predation, desiccation, and metabolic expenditure associated with close-range inspection and rejection of non-hosts (Gries *et al.* 1989; Schroeder 1992).

By preventing host-seeking *G. retusus* from landing at or near attractive sources, disruptant green leaf alcohols offer considerable promise as log protectants, possibly in combination with attractant-baited traps if used in a push-pull treatment (Lindgren and Borden 1993). Although *G. sulcatus* is strongly repelled by the same green leaf alcohols that disrupt *G. retusus* (Deglow and Borden 1998), *T. lineatum* on the BC coast is not (Borden *et al.* 1997). Therefore other non-host volatiles, e.g. bark volatiles (Borden *et al.* 1998), might be needed in a formulation that would be equally effective on all three species of ambrosia beetles.

Further research is necessary to determine if attractive aldehydes or other compounds actually occur in attractive hosts, and if such compounds could be used to enhance the power of attractant-baited traps in IPM of ambrosia beetles.

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# Green leaf volatiles disrupt responses by the spruce beetle, *Dendroctonus rufipennis,* and the western pine beetle, *Dendroctonus brevicomis* (Coleoptera: Scolytidae) to attractant-baited traps

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## ABSTRACT

We tested the hypothesis that green leaf volatiles (GLVs) disrupt the response of spruce beetles, *Dendroctonus rufipennis* Kirby, and western pine beetles, *Dendroctonus brevicomis* LeConte, to attractant-baited traps. Two green leaf aldehydes, hexanal and (*E*)-2-hexenal, reduced the number of spruce beetles captured to intermediate levels and one green leaf alcohol, hexanol, significantly reduced spruce beetle trap catches. Together, the green leaf alcohols and aldehydes reduced trap catches by 78.7 and 89.3% for males and females, respectively. The green leaf aldehyde, (*E*)-2-hexenal, and two green leaf alcohols, (*E*)-2-hexen-1-ol and (*Z*)-2-hexen-1-ol, significantly reduced the numbers of male western pine beetles captured and the latter compound also reduced the numbers of female western pine beetles captured. The greatest disruptive effect for the western pine beetle was 46.7% for (*Z*)-2-hexen-1-ol on males. These results support the hypothesis that GLVs common to non-host angiosperms are disruptive to pheromone and kairomone attraction of conifer-attacking bark beetles. While general GLVs are disruptive to several scolytid species, the most disruptive individual GLV components and blends differ by scolytid species and may reflect differences in the volatile characteristics of their particular ecosystems.

**Keywords:** Spruce beetle, *Dendroctonus rufipennis*, western pine beetle, *Dendroctonus brevicomis*, Coleoptera, Scolytidae, antiaggregant, green leaf volatiles, 1-hexanol, hexanal, (*E*)-2-hexenal, (*E*)-2-hexen-1-ol, (*Z*)-2-hexen-1-ol.

## INTRODUCTION

Volatile stimuli associated with host and non-host plants are important in mediating behavioral responses by phytophagous insects (Visser 1986). Most bark beetles are monophagous or oligophagous, attacking only one or a few species within a genus (Sturgeon and Mitton 1982). Suitable hosts are characteristically well scattered throughout mixed species forests, and are distributed unevenly in space and time (Atkins 1966). Therefore, bark beetles commonly utilize specialized and complex semiochemical messages, including host kairomones and aggregation pheromones to locate suitable breeding material (Borden 1985).

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In seeking suitable hosts, bark beetles encounter and reject many unsuitable hosts and non-host trees. Rejection can be based on a lack of host characteristics or the presence of repellent or deterrent stimuli. Some of the latter stimuli may be green leaf volatiles (GLVs), six carbon alcohols, aldehydes, and derivative esters that are general odor components commonly found in green plants (Visser *et al*. 1979; Whitman and Eller 1990). While GLVs occur across a wide variety of plant families, they are especially abundant in herbaceous plants and deciduous shrubs and trees (Visser *et al*. 1979).

GLVs have been the focus of several recent studies demonstrating that compounds commonly found in non-host angiosperms reduce attraction of conifer-attacking bark beetles to attractant-baited traps. Hexanal and 1-hexanol disrupted attraction of the southern pine beetle, *Dendroctonus frontalis* Zimmermann, to traps baited with attractant semiochemicals and hexanal had a similar effect on the eastern five-spined ips, *Ips grandicollis* (Eichhoff), and the small southern pine engraver, *Ips avulsus* (Eichhoff) (Dickens *et al*. 1992). A blend of four green leaf alcohols disrupted attraction by the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, to pheromone-baited traps, whereas, a blend of two green leaf aldehydes was inactive (Wilson *et al*. 1996). The two most disruptive alcohols, ($E$)-2-hexen-1-ol and ($Z$)-3-hexen-1-ol, reduced the number of mountain pine beetles captured in attractant-baited traps to levels found in unbaited control traps and also reduced attacks on attractant-baited trees. Green leaf alcohols have also been shown in trapping experiments to disrupt the response to aggregation pheromones by conifer-infesting ambrosia beetles, including the striped ambrosia beetle, *Trypodendron lineatum* (Olivier) (Borden *et al*. 1997), *Gnathotrichus sulcatus* (LeConte), and *G. retusus* (LeConte) (Deglow and Borden 1998a, b). For *T. lineatum* and *G. sulcatus* the two aldehydes, hexanal and ($E$)-2-hexenal, enhanced the response to pheromone (Borden *et al*. 1997; Deglow and Borden 1998a). An exception occurs for the bark beetle, *Pityogenes knechteli* Swaine, which uses 1-hexanol as a male-produced multifunctional pheromone (Savoie *et al*. 1998). Finally, 1-hexanol was one of four disruptant volatiles for the mountain pine beetle that were collected from the bark of trembling aspen, *Populus tremuloides* Michx., the most common non-host angiosperm associated with the beetle's principal host, lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann (Borden *et al*. 1998). It was the only component that was disruptive on its own.

The disruptive effects of common GLVs on attraction of the southern pine beetle (Dickens *et al*. 1992) and the mountain pine beetle (Wilson *et al*. 1996) suggest that they might also be effective disruptants for other important tree-killing *Dendroctonus* spp. Two of these in Western North America are the spruce beetle, *Dendroctonus rufipennis* Kirby, and the western pine beetle, *D. brevicomis* LeConte. The spruce beetle is the most destructive insect pest of mature spruce forests throughout its range (Safranyik 1988), and the western pine beetle is the most damaging insect affecting growth and yield of ponderosa pine, *Pinus ponderosa* Laws (Smith 1990). Our objectives were to test common GLVs, alone and combined, as potential disruptants for the spruce beetle and the western pine beetle.

## MATERIALS AND METHODS

In 1995 and 1996, six field trapping experiments (Exp.) were conducted with 12-unit multiple funnel traps laid out in randomized complete blocks with at least 15 m between traps. A small section of vapona no-pest strip was placed in each trap to kill captured insects.

Exp. 1-3 tested the effect of common GLVs (Table 1) on the spruce beetle. They were conducted in mature stands of Engelmann spruce, *Picea Engelmannii* Parry, and subalpine fir, *Abies lasiocarpa* (Moench.) Voss, near Princeton British Columbia. Spruce beetle lures (Phero Tech Inc., Delta, BC) consisted of the aggregation pheromone frontalin (1,5-dimethyl-6,8-dioxabicyclo[3.2.1]octane) and the host kairomone α-pinene (2,6,6-trimethyl-bycyclo[3.1.1]hept-2-ene), with release rates as in Table 1. Exp. 1, conducted from 20 April to 5 June 1995, compared the disruptive effect of green leaf aldehydes, alcohols, or both added to spruce beetle lures. It comprised 10 replicates of five treatments: 1) unbaited control, 2) spruce beetle lure, and spruce beetle lures with 3) green leaf alcohols, 4) green leaf aldehydes, or 5) the full GLV blend. Exp. 2, conducted at the same time as Exp. 1, tested the two green leaf aldehydes alone and combined against the spruce beetle lure, with 10 replicates of five treatments: 1) unbaited control, 2) spruce beetle lure, and spruce beetle lures with 3) hexanal, 4) (*E*)-2-hexen-1-al, or 5) both green leaf aldehydes. Exp. 3, conducted from 18 June to 2 July 1996, tested the four green leaf alcohols alone and combined against spruce beetle lure, with seven replicates of seven treatments: 1) unbaited control, 2) spruce beetle lure, and spruce beetle lures with 3) hexanol, 4) (*E*)-2-hexen-1-ol, 5) (*Z*)-2-hexen-1-ol, 6) (*Z*)-3-hexen-1-ol, or 7) all green leaf alcohols.

**Table 1**

Description of semiochemicals employed in trapping experiments for the spruce beetle and western pine beetle.

| Semiochemical | Source[a] | Release Device[b] | Release Rate mg per 24 hr |
|---|---|---|---|
| frontalin | Phero-Tech | 400 µl Eppendorf | 2 |
| α-pinene | Phero-Tech | 1.5 ml Eppendorf | 50-80 |
| *exo*-brevicomin | Phero-Tech | 400 µl Eppendorf | 1.7 |
| myrcene | Phero-Tech | 15 ml polyethylene bottle | 15-25 |
| hexanal | Aldrich | bubble cap | 13 |
| (*E*)-2-hexenal | Aldrich | bubble cap | 13 |
| 1-hexanol | Aldrich | bubble cap | 4 |
| (*E*)-2-hexen-1-ol | Aldrich | bubble cap | 4 |
| (*Z*)-2-hexen-1-ol | Bedoukian | bubble cap | 4 |
| (*Z*)-3-hexen-1-ol | Aldrich | bubble cap | 4 |

[a] Aldrich = Aldrich Chemical Company, Milwaukee, WI; Bedoukian = Bedoukian Research Inc., Danbury, CT.

[b] Release devices prepared by Phero-Tech, Inc., Delta, BC with semiochemicals stabilized with 1.2% (wet weight) Ethanox® 330 antioxidant, Ethyl Chemicals Group, Baton Rouge, LA. Release rates determined in the laboratory at 20 °C.

Exp. 4-6 were similar to Exp. 1-3, except that they tested whether attraction of the western pine beetle was disrupted by GLVs and were set up in ponderosa pine stands near Nelson, BC. The attractive lure consisted of the pheromones *exo*-brevicomin (*exo*-7-ethyl-5-methyl-6,8-dioxabicyclo[3.2.1]octane) and frontalin (1,5-dimethyl-6,8-dioxabi-cyclo[3.2.1] octane) plus the host kairomone myrcene (2-methyl-6-methylene-2,7-octadiene) with release rates as in Table 1. Treatments were identical to those for Exps. 1-3, respectively, except that western pine beetle lures replaced spruce beetle lures. Numbers of replicates and dates were as follows: Exp. 4, 10 replicates from 3-10 June and

10 replicates from 15-19 July 1996;   Exp. 5, 10 replicates from 10-14 June  and 10 replicates from 19-24 July 1996; Exp. 6, 24 replicates with six replicates at a time conducted in 3 to 8 day periods during 14-29 June 1996.  For experiments in which replicates were conducted in multiple time periods, all lures were collected after the initial set of replicates, and the experiments were repeated with additional replicates laid out in new randomized complete blocks.

Insects captured in all experiments were collected at regular intervals and held at -18°C until counted and sexed.  The numbers of insects captured were transformed by $\log_{10} (x+1)$  and analyzed by ANOVA (GLM procedure, SAS Institute Inc. 1990) for a randomized complete block design, treating replicates as blocks.  For Exp. 4-6, in which replicates were conducted over 2 or more time periods, time was included as a blocking factor.  The Ryan-Einot-Gabriel-Welsch multiple Q-test (REGW test) (SAS Institute Inc. 1990, Day and Quinn 1989) was used to determine differences between treatment means in all experiments.

## RESULTS

The complete blend of all six GLVs in Exp. 1 caused 78.7 and 89.3% reduction of spruce beetle males and females, respectively, in attraction to spruce beetle lures and reduced the number of beetles captured to levels that did not differ significantly from those in unbaited control traps (Fig 1a).  Neither the aldehyde nor the alcohol blends significantly reduced trap catches.  Trap catches in Exp. 2 were reduced by the two green leaf aldehydes alone or together to levels that were statistically intermediate between those in unbaited control traps and in traps baited with spruce beetle lures alone (Fig 1b). In Exp. 3, there were no significant differences between treatments for males, but attraction of females was significantly reduced by 1-hexanol (Fig. 1c).  The highest numbers of females captured were in traps baited with spruce beetle lures alone.  The numbers of females captured in all other treatments, including unbaited control traps, were at statistically intermediate levels, except captures in traps with spruce beetle lures plus $(Z)$-3-hexen-1-ol, which did not differ from spruce beetle lures alone.  The total numbers of spruce beetles captured were 436, 1189, and 335 in Exp. 1-3, respectively.

For the western pine beetle, the responses to GLVs were weak and inconsistent.  The aldehyde $(E)$-2-hexenal significantly reduced the number of males captured in Exp. 5 (Fig. 2b).  In Exp. 6, $(Z)$-2-hexen-1-ol significantly reduced the number of beetles of both sexes captured and $(E)$-2-hexen-1-ol reduced the numbers of males.  The complete alcohol blend reduced the numbers of males captured in Exp. 6, but not in Exp. 4 (Fig. 2a,c).  The maximum reduction achieved was 46.7% for $(Z)$-2-hexen-1-ol on males.  The total numbers of western pine beetles captured were 4237, 4727, and 32,081  in Exp. 4-6, respectively.

## DISCUSSION

The results for the western pine beetle differ from those for the spruce beetle. Whereas, attraction of both male and female spruce beetles was strongly disrupted by the full GLV blend (Fig 1a), no such reduction was seen for the western pine beetle (Fig. 2a). For the spruce beetle, no reduction in attraction was seen for the aldehyde blend or the alcohol blend, suggesting that some combination of both alcohols and aldehydes is required to achieve significant disruption.  No aldehyde and only one alcohol  was active
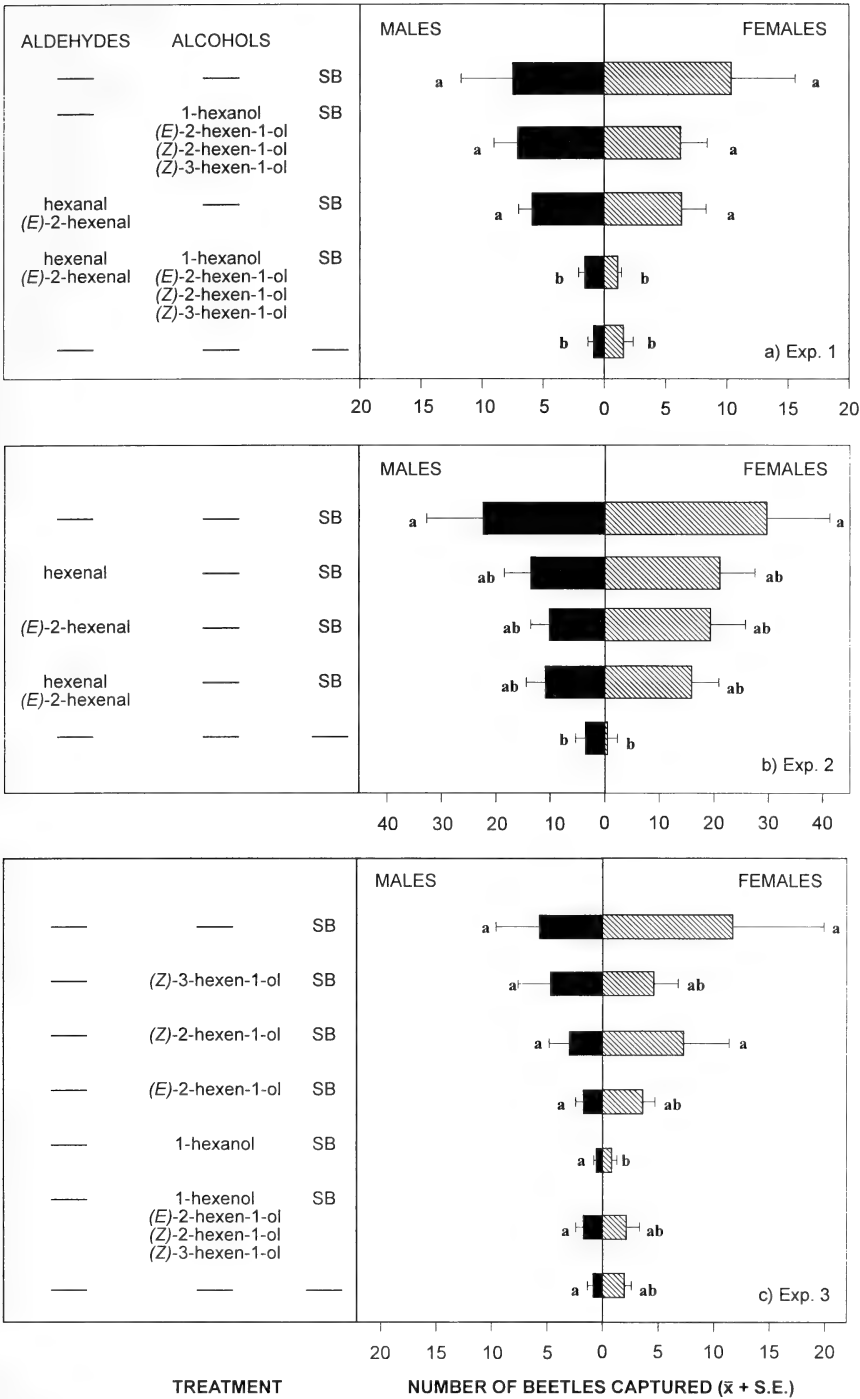
**Figure 1.** Effect of GLVs released, as in Table 1, on the capture of male and female spruce beetles in attractant-baited multiple funnel traps in Exp. 1 and 2, Arastra Creek, and Exp. 3, Lawless Creek, near Princeton, BC. Spruce beetle lures (SB) consisted of frontalin and $\alpha$-pinene released as in Table 1. $N=10$, 10 and 7 for Exp. 1-3, respectively. Bars for each sex with the same letter are not significantly different, REGW test, $P<0.05$.
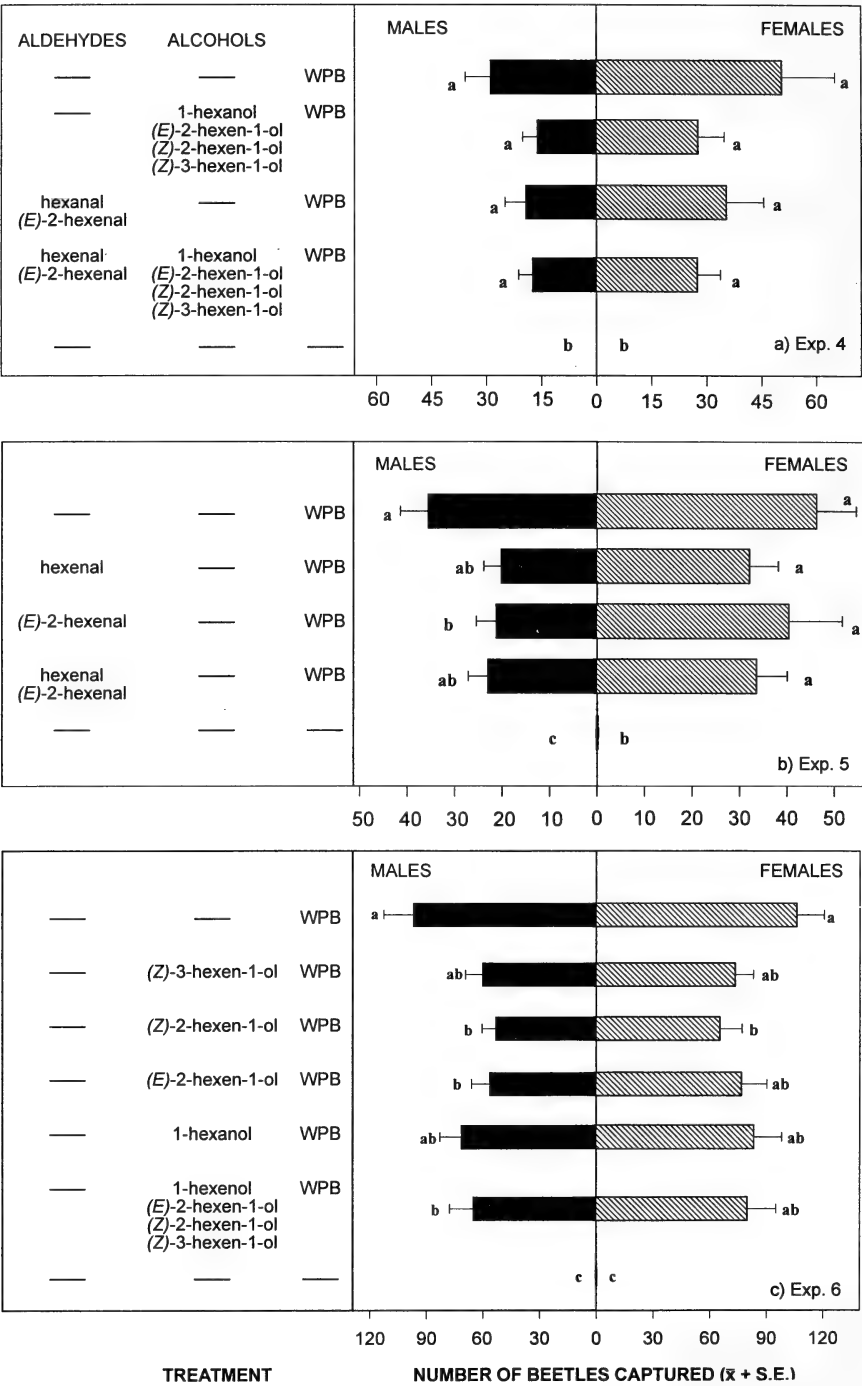
**Figure 2.** Effect of GLVs released, as in Table 1, on the capture of male and female western pine beetles in attractant-baited multiple funnel traps in Exp. 4-6, near Nelson, BC. Western pine beetle lures (WPB) consisted of *exo*-brevicomin, frontalin and myrcene released as in Table 1. *N*=20, 20 and 24 for Exp. 4-6, respectively. Bars for each sex with the same letter are not significantly different, REGW test, *P*<0.05.

alone against the spruce beetle, but one aldehyde and two alcohols were active alone against the western pine beetle. The weak and inconsistent responses by the western pine beetle to GLVs are typical of those to stimuli of low bioactivity offered at threshold doses.

The results for the spruce beetle and western pine beetle further contrast with the congeneric mountain pine beetle and southern pine beetle. Neither of the aldehydes was disruptive for the mountain pine beetle, and all of the alcohols were disruptive, with the two most effective being (E)-2-hexen-1-ol and (Z)-3-hexen-1-ol (Wilson *et al.* 1996). For the southern pine beetle, both 1-hexanol and hexanal were disruptive (Dickens *et al.* 1992), but neither was effective against the western pine beetle, and only 1-hexanol disrupted the response of the spruce beetle (Figs. 1, 2).

The increased deterancy of spruce beetle attraction by the full GLV blend compared to the alcohols, aldehydes or individual components suggests an additive or dose dependent effect of the combined stimuli. The individual GLV components may have similar dose-dependent disruptive effects, thus differences in response to the full blend may be due to the higher overall release rate of the combined GLVs.

Our results for the spruce beetle and western pine beetle are consistent with the hypothesis that GLVs common to non-host angiosperms are disruptive to conifer-attacking bark and ambrosia beetles. As summarized by Deglow *et al.* (1998a) the pheromone-positive responses of 10 species of conifer-infesting scolytid beetles are now known to be disrupted by green leaf volatiles, presumed to be produced by non-host angiosperms, and for *P. knechteli* 1-hexanol is a repellent pheromone at doses $\geq$ 15 mg per 24 h (Savoie *et al.* 1998). It would be adaptive for these beetles to recognize and avoid general volatile compounds that are commonly found in a wide variety of non-host deciduous and herbaceous species rather than recognizing precise species-specific volatiles for each non-host species (Borden *et al.* 1998). In this way, several species of non-host trees with partially overlapping blends of common volatile compounds could be perceived and avoided during host location. On the other hand, certain specific compounds found in host trees and the most prevalent non-host species could be important for close range host selection. Precise blends of specific host and pheromone components would further enhance specificity in host selection and maintain breeding isolation between sympatric species of bark beetles.

Only for the mountain pine beetle do GLVs appear to be sufficiently potent to have the potential when used alone to be operationally effective in deterring attack (Wilson *et al.* 1996). For other species, combinations of disruptants, including any or all of GLVs, other non-host compounds, antiaggregation pheromones, repellent synomones, and resistant host kairomones may be required for optimal protection of hosts from attack (Borden 1997).

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# Trapping mountain pine beetles *Dendroctonus ponderosae* (Coleoptera: Scolytidae) using pheromone-baited traps: effects of trapping distance

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## ABSTRACT

Mountain pine beetles (*Dendroctonus ponderosae* Hopkins) were released and recaptured using pheromone-baited Lindgren traps at various distances from the release point to determine the effects of distance on trapping effectiveness. Very few beetles were recaptured more than 500 m from the point of release, although this may have been due to interference by intervening traps. Trapping effectiveness depended on trap location, date of release, wind speed and distance from the point of release. Between 2 and 3% of the released beetles were recaptured in total.

**Key words:** Mountain pine beetle, pheromone trapping, dispersal

## INTRODUCTION

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is a highly destructive insect pest of mature pine forests in western North America (Safranyik *et al.* 1974). Beetles instigate pheromone-mediated mass attack of pine trees, killing them when the attack level is high enough or when the resistance of the trees is low, or both. Traps baited with only the beetle pheromone components, *exo*-brevicomin and *trans*-verbenol, are not very attractive to beetles, but the standard mountain pine beetle bait containing a combination of *exo*-brevicomin, *trans*-verbenol and .the tree-produced myrcene (PheroTech Inc., Delta, BC) readily catch flying adults, although traps are not as effective as baited trees. Pheromone-baited traps are routinely used to monitor mountain pine beetle populations and to detect the presence of these insects in areas where they may occur only sporadically (Borden 1985). However, the baits may also attract some dispersing beetles into the area and induce some of them that are not captured to attack suitable trees in baited areas. This has led to the concern that the use of monitoring traps without thorough follow-up surveys could lead to establishment of incipient infestations. One question to answer in this respect is "How effective are pheromone-baited traps in capturing mountain pine beetles at various trapping distances?" This question is of interest in other species of bark beetles as well (Turchin and Opendaal 1996; Werner and Holsten 1997) and the experiment described here is aimed at addressing it. We released mountain pine beetles to determine trapping success at various distances from a release point.

## MATERIALS AND METHODS

An area of about 2000 hectares of immature Douglas-fir located 35 kilometres southwest of Williams Lake, BC (Latitude 51° 53' N; Longitude 122 ° 12' W; altitude 1320 m) was selected for the experiment. In this area we established three sites along a

road for beetle release and recapture. Because Douglas-fir is not a host of the mountain pine beetle, the probability of infestations resulting from these releases was minimized. In addition, the trees would not be attractive to the beetles and thus would not interfere with the experiment. Releases were made in July of 1996 prior to the onset of the main flight period of the local beetle population; in 1997 the main flight period had started at the time of the first release.

In late April 1996 we obtained beetle larvae from Saturday Creek, near Princeton, BC, by cutting eight infested lodgepole pine trees and taking the lowest 2-4 metres of the boles back to the laboratory. These were incubated at 20°C until adult beetles emerged. Emerged adults were kept at 6°C in containers with moistened fresh wood shavings until the time of the releases. In early May 1997 beetles were obtained near 100 Mile House, and similarly reared.

At each of the three release-recapture sites we set out three pheromone-baited Lindgren traps across a road and into the forest about 15 m apart; these three traps are referred to as one trap location (M, Fig. 1). Once established, the trap locations did not change during the experiment. We established three release positions at each site based on distance from the trap location. Releases were made at distances of 100 m, 250 m and 500 m downwind (according to the prevailing wind direction) from the trap location M at each site. The three traps were all equidistant from the release position, and thereby represented one distance for the pheromone to be detected; thus trapping distance was not confounded by traps at intermediate distances from the release positions.
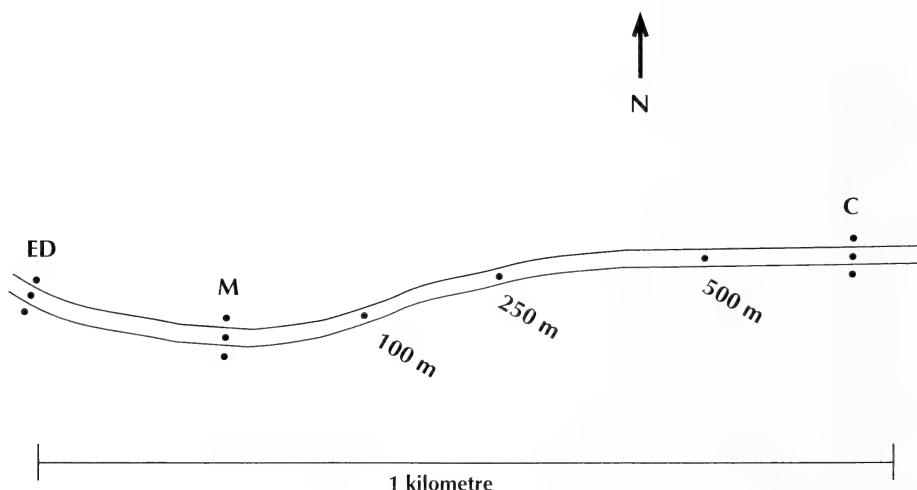


**Figure 1.** The trap locations at site No. 3 near Williams Lake, BC. The trap locations were: ED - extra distance traps, M - main traps, C - conjugate traps. The three distances mark the positions of the release platforms relative to M.

Releases were made from platforms consisting of a wooden frame with a fine-mesh screen bottom and a chicken-wire covering to keep out birds and dragonflies; these platforms were 1m above the ground. In 1996 we made nine releases, three on each of 3 release days, with one release at each site on a given day. Each release was at one of the three release positions with a different release distance at each site and with approximately 1300 beetles per release. At a given site a different distance was used on each release day. The prevailing wind was from the west, and came straight down the

road, being funneled down by the trees on each side. Wind speed was measured using an anemometer at the times of release. We thought that releases every second day would make trapping from the different releases effectively independent of each other. Thus, our releases were made on July 10, 12 and 14 in mid morning.

Initially we monitored the traps every 2 hours to count recaptured beetles, but later reduced that to three times a day due to low capture rates. Since the number of beetles released varied somewhat, the recaptures were adjusted by multiplying by "1300 divided by those released", as the average number per release was about 1300.

In 1997 we repeated the experiment, except that two sets of traps were set up on opposite sides of the release positions (Fig. 1) because the wind was quite variable in 1997 and there was no guarantee that the trap positions that yielded substantial numbers of beetles in 1996 would again be effective in 1997. Otherwise the same design was used as in 1996. In addition, because beetles were caught at 500m in 1996, an additional three traps were set out 250m beyond the main traps in site no. 3 in 1997. The traps at the locations used in 1996 were referred to as the 'main' traps, those on the other side of the release locations (750m down the road to the east of the main traps) were referred to as the 'conjugate' traps, and those 250m beyond the main traps in site no. 3 were referred to as the 'extra-distance' traps, being 750 m from the farthest release platform in that site (Fig. 1). The traps remained at those locations while the releases were made from the three different distances (100m, 250m and 500m) from the main traps, with corresponding distances from the conjugate traps being 650m, 500m and 250m respectively. Although the inclusion of more traps allows the potential for confounding of trap effects to occur, if the wind were blowing from the direction of the conjugate traps, the beetles would only receive pheromone from those traps. If the wind were blowing from the direction of the main traps, then the extra-distance traps (at one site only) might introduce some confounding at that trap location and this would presumably be more of a problem for the 100 m trapping distance than for the longer distances. The other two trap sites would be unaffected because there were no extra-distance traps at those sites. In 1996 the beetles were not colour-coded, whereas in 1997 beetles were coloured (Linton *et al.* 1987) with fluorescent powder (Day-Glo Inc.) prior to release and beetles on each release day were coloured differently.

The numbers caught in the three traps at each location were summed to provide one datum. The data were pooled for a given factor and all the results were analyzed using $\chi^2$ analysis.

## RESULTS

In 1996, 12,500 beetles were released and 206 beetles were recaptured, while in 1997, 9,000 beetles were released and 276 were recaptured. In 1996 both the date of release ($\chi^2 = 43.3$; df = 2; $p < 0.001$) and the trap location ($\chi^2 = 19.3$; df = 2; $p < 0.001$) were important in determining recaptures. Pooling over other factors, the numbers captured from the July 10, 12 and 14 releases were 25, 98 and 83 respectively. Similarly, the numbers captured at the east, centre and west trap sites were 73, 41 and 92 respectively. Wind speed may have influenced catches on different release days. At wind speeds (i) $\leq$ 2, (ii) 3-5, and (iii) > 5 km/h, captures were 69, 100 and 37 respectively. Intermediate wind speeds (3-5 km/h) were most conducive to recapturing beetles ($\chi^2 = 28.8$; df = 2; $p < 0.001$). In 1997 both the speed and direction of the wind were highly variable and probably were largely responsible for the poorer results obtained that year. The effects of distance were significant in both years; $\chi^2$ for 1996 was 12.2 and for 1997 was 17.8,

although the 250 m and 500 m distances did not separate for 1997. Fewer beetles were caught in the conjugate traps than in the main traps ($\chi^2$ = 109.1; df = 1; $p$ < 0.001), indicating that the main traps were the most effective, even with the variable winds (Fig. 2). Since the extra-distance traps were only at one site, the comparisons are shown in Table 1. Fewer beetles were caught at the extra-distance traps than at the main traps and all the extra-distance traps caught fewer than the main traps did at the 500 m distance.
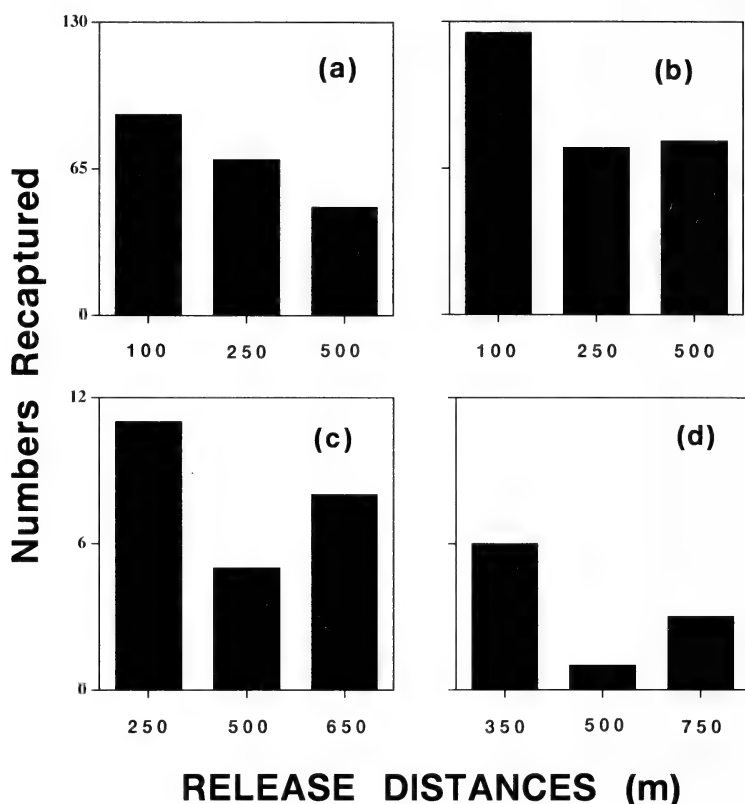


**Figure 2.** Numbers of beetles recaptured from releases at each of the three distances. (a) The traps in 1996; (b) the main traps in 1997; (c) the conjugate traps in 1997; (d) the extra-distance traps in 1997.

A problem that became apparent in 1996 was the assumption that captures would reflect only the most recent releases. Beetles from the previous release were still being recaptured 48 hours later on the morning of a subsequent release, and catches at 500 m following another release followed a suggestive pattern. The release at 500 m that followed a release at 100 m had the highest recapture rate of the three 500-m releases (taken as a proportion of the recaptures from all three locations on that date), while the release at 500 m following the 250 m release had the lowest proportional recapture rate. This suggests that some of those recaptured at traps 500 m distant from the most recent release may have been left over from the release at 100 m distance two or three days before, and since the beetles in 1996 were not colour-coded, this could not be tested directly. However, the time sequences of captures for both 1996 and 1997 show that the trap yields in the mornings were greater than later in the day (Fig. 3) indicating that most

captures occurred between 4 pm and 9 am the following morning. In addition, in 1997 few marked beetles were captured after the morning of the third day (release being on the first day). Thus it seems probable that few beetles were recaptured after the morning of the third day in the 1996 trials as well and that the beetles recaptured for each 2 day period were mostly the results of releases within that time period.
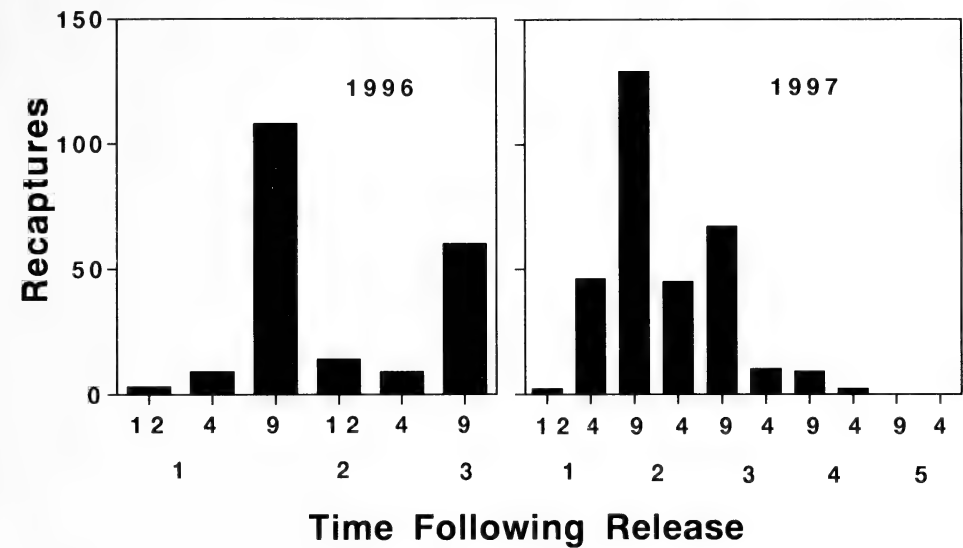
Figure 3. Time sequences of recapture for the 1996 and 1997 release periods. The horizontal axis shows the hour of collection (upper numbers; 12 noon, 4 pm, 9am) and the day of collection after release (lower numbers). Releases were made about 10 am on day one.

**Table 1**

Number of beetle recaptures from the main traps and the extra distance traps in 1997. All numbers are from the same site.

| Trap type | Release Period | Distance (m) | Recaptures |
|---|---|---|---|
| | 1 | 100 | 26 |
| Main | 3 | 250 | 16 |
| | 2 | 500 | 32 |
| | 1 | 350 | 6 |
| Extra Dist. | 3 | 500 | 1 |
| | 2 | 750 | 3 |

## DISCUSSION

Differences among trap sites are obviously quite important to the success of the trapping experiments. This may relate to the direction of the road at each site; at two sites the road ran E-W, at the third site it ran NW-SE. Also, differences between release dates were important. Differences in captures correlated with wind speed, and although we could not manipulate wind speed, the correlation strongly suggests that wind speed influences the ability of beetles to find the traps. The differences in release dates presumably relates to differences in weather conditions (mainly wind) on the three release

days, although other factors may also have been involved. Although the beetles were not colour-coded in 1996 and it was thus impossible to separate the catches from different release dates, it is probable that most of the beetles recaptured within a given 2-day time period resulted from beetles released on day one of the period. Safranyik *et al.* (1992) found that over 80% of released and recaptured mountain pine beetles were captured within 3 days of release regardless of temperature and wind direction. In addition, our finding that most trap captures occurred between 4 pm and 9 am the following morning agrees with the finding of Rasmussen (1974) that the maximum flight activity was between 4 pm and 6 pm in Utah and Idaho.

The chances of any of the results being caused by the capture of wild beetles endemic to the area were remote in 1996, since the lab-reared beetles were phenologically about 2 or 3 weeks ahead of the wild population. In addition, the use of a non-host stand also helped ensure that there would be few wild beetles present. Two baited traps put out in the experimental area about a month before the releases took place did not trap any mountain pine beetles. However, in 1997 the reared beetles were not ready for release until late July and about half of all beetles captured were wild ones, being non-dyed. The odour of the usual host, lodgepole pine, is important in the attraction of the beetles and this odour was included in the trap baits by adding myrcene. Since the odour of Douglas-fir is unlikely to affect the behaviour of the beetles, the odour of the host trees was only present at the traps. The pheromone would likely be funneled down the corridor (road) between the two rows of trees, rather than being diffused more broadly as it would be if it were travelling through the trees. Thus our results might be seen as an upper limit to trapability, since conditions were close to being ideal for pheromone transport and detection.

Recaptures at the conjugate traps were all fewer than those at the main traps indicating that the up-wind direction was preferred, at least by those beetles that "responded" to the baited traps, even though the wind was quite variable and was sometimes blowing the opposite way at the time of release. There is evidence (Gray *et al.* 1972) that without sources of attraction, beetles disperse passively downwind. Recaptures at the extra-distance traps were also much fewer than at the main traps, even at 500 m, suggesting that the beetles tended not to fly much past the first traps encountered.

Under conditions of little wind, most mountain pine beetle recaptures would be close to the point of release or to brood trees (Safranyik *et al.* 1992). However, where wind is stronger, the patterns are not so clear, and beetles may actively fly or be passively carried further, in which case the dispersal distances can be quite long. Safranyik *et al.* (1992) only captured about 1% of the total recaptured marked and released mountain pine beetles 250 m from the release point under the canopy of a mature lodgepole pine stand; the rest were recaptured closer to the release point. We conjecture that even with stronger wind, a very small proportion of beetles would respond directly to traps located more than 1 km from their point of release.

## ACKNOWLEDGEMENTS

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# New *Oncocnemis* (Lepidoptera: Noctuidae) from the Pacific Northwest*

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## ABSTRACT

Nine Pacific Northwest *Oncocnemis*, *O. coprocolor*, *O. chalybdis*, *O. greyi*, *O. saxatilis*, *O. mus*, *O. parvacana*, *O. satanella*, *O. tartarea*, and *O. goedeni*, are described as new, and two subspecies, *O. riparia major* Grote and *O. chorda extremis* Smith, are reinstated to species rank. The adults and male genitalia are illustrated.

## INTRODUCTION

A survey by Ken Goeden of the Oregon Department of Agriculture in the 1960's and early 1970's remains the most comprehensive inventory of the noctuid fauna of Oregon. Ongoing surveys in Oregon by Dr. Paul Hammond of Oregon State University (OSU) and in the Pacific Northwest (British Columbia, Washington, and Oregon) by the authors is adding considerably to our knowledge of the region's fauna. Our efforts to catalogue the noctuids of the Pacific Northwest have resulted in the discovery of many taxonomic problems, including the existence of more than thirty undescribed species. Nine of these are members of the genus *Oncocnemis* Lederer.

The characteristic features of *Oncocnemis* have been recently described by Ronkay and Ronkay (1995) in their treatment of the western Eurasian species. Briefly, members of this genus are characterized by the presence of a single large spur on the medial fore-tibiae; male genitalia with a thin, distally-tapered uncus; valvae long, with well-developed corona and cucullus; clasper perpendicular to valve, originating from ventral margin near distal sacculus, curved or S-shaped with a thin, sharply-pointed apex; vesica of aedoeagus curved or twisted, with basal diverticulae and innumerable cornuti arranged in various fields, often with a terminal spine and bristles. There are more than 100 species currently included in the genus (Poole 1989), although some of these may represent undescribed genera (Poole 1994). The genus *Oncocnemis* is holarctic in distribution, with the majority of species in western North America. Species groups are well defined and easily recognized by wing markings and genital characters; however, it is often difficult to separate closely related species within species groups (Ronkay and Ronkay 1995). Many of the species are rare or local, and the genus as a whole is typically poorly represented in collections.

In the present work we make no attempt to revise the generic concept of *Oncocnemis* or deal with the entire nearctic fauna. However, we recognize obvious species groups within which more than two species occur in the Pacific Northwest and provide keys to the identification of the closely related, Pacific Northwest members of the *O. tenuifascia* Smith and *O. figurata* (Harvey) groups. We describe nine new Pacific Northwest species

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and elevate two subspecies, *O. chorda extremis* Smith, and *O. riparia major* Grote to species rank. In the Pacific Northwest, additional problems are likely present in the *O. melantho* Smith, *O. simplex* Smith, and *O. riparia* Morrison groups. These problems are not dealt with here because many of the species and subspecies in these groups are widely distributed and because there is only limited Pacific Northwest material available for study. We do not illustrate or diagnose female genitalia in the present work. Characters of the female genitalia are useful in determining species groups and genera but are of little help in distinguishing species in closely related species complexes. Terminology for internal and external characters follows Lafontaine (1987).

**New Pacific Northwest *Oncocnemis*.**

1. *Oncocnemis coprocolor* **sp. n.**
        (Figures 1d, 2e, 3e)

**Type locality**. Canada, British Columbia, BC Hydro Dam, E. end of Seton Lake.
**Type material**. Holotype male: Canada, British Columbia, Hwy 99 at BC Hydro Dam, E. end of Seton Lake, 250 m, 3 VI 1995, J. Troubridge, in the Canadian National Collection (CNC). Paratypes: 13 ♂ ♂: **Washington**: 2 ♂ ♂, Kittitas County, Quartz Mtn, 6,400' [1,950 m], 15 VII 1996, J. Troubridge; 1 ♂, Okanogan County, 340 m, Columbia R. Valley, W. boundary Bridgeport State Park, 29 V 1995, L. and A. Crabo; 4 ♂ ♂, Chelan Co., Junior Point Camp Ground, 2,100 m, 6 VIII 1997, J. Troubridge; 2♂♂, same locality and collector, 18 VII 1998; **British Columbia**: 2 ♂ ♂, Kirby Flats Rd., 50° 32' N 121° 43' W, 12 VI 1998, J. Troubridge; 1 ♂, same locality and collector, 17 VI 1998; **Colorado**: 1 ♂, Mesa County, Colorado Nat. Mon., Upper Red Cyn., 31 V 1997, Rodgers family.
**Description**. Forewing length 13-14 mm. Antennae filiform, scape brown; head with a mixture of cream and black-tipped brown scales, appearing brown; palpi light brown, with a small ventral patch of black scales on the distal second segment; prothoracic collar with four bands: beige basally followed by a thin black line, a wider fawn band, and finally a darker brown band toward the thorax; thorax with a mixture of beige, cream, black and cream-tipped beige and black scales, the tegulae, anterior thorax, and a dorsal tuft adjacent to abdomen darkest, nearly black; abdomen light gray-brown. Dorsal forewing brown, lightest in median area and inside orbicular and reniform spots, black between basal line and antemedial line below cell, dark brown-black with scattered light brown scales between postmedial line and margin, terminal area beyond scalloped brown terminal line black, producing a series of black dots between the veins, fringe checkered with brown and black; basal, antemedial, and postmedial lines incomplete, scalloped, double, black with light brown filling, antemedial line evident below cubitus where it is laterally convex and as dots at costa, postmedial line obscure above cell, oblique, thickened at veins producing a series of black dots, median shade evident only as a dark dot on costa, subterminal line incomplete, scalloped, light brown; reniform and orbicular spots faint, brown, evident mostly due to light brown filling, orbicular elliptical, reniform broad. Dorsal hindwing cream with darker base, discal dot, and veins, with a wide brown-black terminal band; fringe brown basally, white terminally.
**Male genitalia**. Valve (Figure 3e) relatively broad, 3.2x as long as wide, widest from clasper to cucullus, dorsal cucullus rounded; clasper 3/5x as long as valve width ending well below costa, S-shaped and talon-like with widened mid-section. Vesica (Figure 2e) bends sharply dorsad and to the right; a small basal diverticulum occurs on the left; a ribbon of sparse, spine-like cornuti extends from dorsal surface at diverticulum to apex where it curves to the left onto ventral surface; a dense patch of prostrate spine-like cornuti is present on the dorsal 2/3 of vesica; one large apical cornutus is present.

**Female genitalia**. Unknown.

**Derivation of the name**. The name is derived from the Greek word *kopros*, meaning dung. This brownish species is one of the least handsome members of the genus.

**Diagnosis**. There are no other species in the Pacific Northwest that could be confused with *O. coprocolor*. The most closely related species, *O. terminalis* Smith (Figure 1e) (HT Michigan State University [photograph examined]), occurs in the south-central USA and can be separated from *O. coprocolor* by the presence of distinct orbicular and reniform spots which are nearly obsolete in *O. coprocolor*.

**Distribution and habitat**. *Oncocnemis coprocolor* has been found in arid areas in the Fraser River Canyon near Lillooet, BC, at one location in the northern Columbia Basin near Bridgeport, Washington, on two mid-elevation ridges in the central Washington Cascades, and in Mesa Co., Colorado. It flies in late spring at lower elevations and in mid summer in the mountains.

2. *Oncocnemis chalybdis* **sp. n.**
      (Figures 1r, 2h, 3k)

**Type locality**. USA, Washington, Table Rock, Columbia Co., 46° 01' N 117° 54' W.

**Type material**. Holotype male: Washington, Table Rock, Columbia Co., 46° 01' N 117° 54' W, 1,900 m, 14 VIII 1998, J. Troubridge, in the CNC. Paratypes: 7 ♂♂, 4 ♀♀: **British Columbia**: 1 ♀, Kirby Flats Rd., 50° 32' N 121° 43' W, 20 VIII 1998, J. Troubridge; 1 ♂, Watch Peak, 50° 28' N 116° 18' W, 2,500 m, 24 VII 1998, J. Troubridge; **Montana**: 1 ♂, 17 mi. S.W. of Kalispell, 3,800' [1,200 m], 23 VIII 1961, D. F. Hardwick; **Washington**: 1 ♀, same data as holotype; 1 ♂, Pierce-Yakima Co. Line, Chinook Pass at Pacific Crest Trail, 1,700 m, 14 VIII 1990, L. and A. Crabo; 1 ♂, Yakima Co., Bethel Ridge, 2,000 m, 22 VIII 1997, J. Troubridge; 1 ♀, same locality and collector, 18 VIII 1995; 1 ♂, 1 ♀, same locality and collector, 27 VIII 1998; 1♂, same locality, 3 IX 1997, L. Crabo; **Oregon**: 1 ♂, Jefferson Co., Green Ridge, Prairie Farm Meadow, larva collected 7 VII 1993, ex. *Spiraea douglasii* Hook, J. Miller.

**Description**. Males and females similar. Forewing length 15-17 mm. Antennae filiform; head, palpae, and scape charcoal gray; prothoracic collar charcoal gray basally, edged with white; thorax charcoal gray, with white scales in posterior tegulae and in dorsal tuft; abdomen gray. Dorsal forewing steel gray, median area posterior to cubital vein, postmedial space adjacent to subterminal line, and a spot in subterminal space at anal angle charcoal, median area anterior to cubital vein medium gray; basal, antemedial, and postmedial lines thick, even, black, antemedial line a laterally convex arc, postmedial line undulating; median shade charcoal, evident only anterior to cubital vein, postmedial line irregular, indistinct, evident only due to adjacent charcoal in postmedial space; terminal line black; thin black basal dash at base of cell, eight long black lines between veins from mid subterminal space to margin; claviform spot small, solid black, other spots absent; fringe medium gray, checkered with dark gray between veins. Dorsal hindwing white with black costal and anal margins, with broad sharply defined very dark gray terminal band; fringe gray basally, white terminally.

**Male genitalia**. Valve (Figure 3k) widest distally, 4x as long as wide, dorsal cucullus triangular; clasper relatively short, 2/5x as long as valve width, thorn-shaped, widest at the base. Vesica (Figure 2h) bends slightly to the left before turning 90° downward, relatively short and wide (2/3 as long as aedeoagus); a patch of short cornuti is present on the left side at mid vesica; a dense patch of long cornuti on right side extends from the base almost to the apex; a single, long, apical cornutus extends posteriorly perpendicular to vesica; small diverticulae are present on the left at the base and ventrally near the apex.

**Female genitalia**. Ovipositor lobes rounded, covered with setae; ductus bursae heavily

sclerotized; corpus bursae bisaccate with anterior chamber bulbous, tapered anteriorly, deeply furrowed with two elongate lateral signa and broadly connected to the irregular posterior chamber; small appendix bursae arises ventrally from posterior chamber and gives rise to ductus seminalis.

**Diagnosis**. This species cannot be confused with any other species in western North America. The closely related *O. piffardi* Walker (Figure 1q) occurs east of the Rocky Mountains. These species can be separated by the thoracic collar, which is black in *O. piffardi* and edged with white in *O. chalybdis*. In addition, the median area of the dorsal forewing of *O. piffardi* is black, while that of *O. chalybdis* is charcoal and medium gray with visible median band and claviform spot. Also, *O. chalybdis* has a black terminal line, absent in *O. piffardi*, and a checkered fringe, which is solid dark gray in *O. piffardi*. Internally, the apical cornutus of *O. chalybdis* is longer (1.5 mm) and more massive than that of *O. piffardi* (1.0 mm) (Figure 2g), and the clasper of *O. chalybdis* tapers evenly from base to apex, while that of *O. piffardi* (Figure 3l) is slightly swollen subbasally. The male genitalia of these North American species are closely similar to those of *O. senica* (Eversmann) which is widely distributed in eastern Eurasia.

**Derivation of the name**. The name is Latin, meaning steel, and refers to the shiny gray colour of the dorsal forewing.

**Distribution and Habitat**. *Oncocnemis chalybdis* has been collected at mid elevations (1,200-2,000 m) from the foothills of the Rocky Mountains in Alberta, westward to the east slopes of the British Columbia Coast Range and the Oregon and Washington Cascades. Larvae have been collected from on *Spiraea douglasii* Hooker (Miller, 1995; J. Troubridge) and reared to adults; however, *Spiraea densiflora* Nuttall and particularly *Spiraea stevenii* Schneider are usually the only *Spiraea* species present in its habitat.

## The *O. figurata* group

Members of the *figurata* group have gray or gray-brown forewing colour, lack the ordinary forewing spots, have thin black forewing lines with the antemedial and postmedial lines joined across the median space by a straight black line, and lack a well defined dark terminal band on the dorsal hindwing. Four species of this group are found in the Pacific Northwest: *O. figurata, O. semicollaris* Smith (HT American Museum of Natural History [examined]), *O. ragani* Barnes, and *O. greyi* n. sp. *Oncocnemis figurata* is widely distributed east of the Cascade Mountains in Washington and Oregon. *Oncocnemis ragani* is limited to southwest Oregon. *Oncocnemis semicollaris* is found in the vicinity of the Gulf of Georgia and east of the Cascades from south-central British Columbia to central Oregon. The distribution of the new species, *O. greyi*, is contained in its description, below.

**Key to the Pacific Northwest species of the *figurata* group**
1. Head gray . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *O. semicollaris*
- Head black . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .2
2. Basal dash absent. Terminal area of forewing gray-brown . . . . . . . . . . . . . . . . . .*O. greyi*
  - Basal dash present, extending from wing base to antemedial line. Forewing colour gray
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .3
3. Dorsal hindwing pearlescent white . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .*O. ragani*
- Dorsal hindwing gray . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .*O. figurata*

3. *Oncocnemis greyi* **sp. n.**
          (Figures 1v, 2j, 3a)

**Type Locality**. Canada, British Columbia, E. end of Seton Lake, base of Mt. McLean.

**Type material**. Holotype male: Canada, British Columbia, E. end of Seton Lake, base of Mt. McLean, 5 VII 1996, J. Troubridge, in the CNC. Paratypes: 89 ♂♂, 23 ♀♀: **Washington**: 8 ♂♂, Stevens Co., Columbia R. Valley, 3.5 mi N. of Cedonia on Dissell Rd., 475 m, 22 VI 1990, L. Crabo; 2 ♂♂, 1 ♀, Kittitas Co., Reecer Creek at Johnson Cyn., 900 m, 20 VII 1991, L. Crabo; 1 ♀, Douglas Co., N. slope of Badger Mt. at Creek 3 mi ESE. of Orondo, 1,000 m, 18 VII 1992, L. Crabo; 2 ♂♂, Chelan Co., Entiat Range, Trib. to Swakam Creek, 2 mi S. of Chumstick Mt., 1,250 m, 30 V 1992, A. and L. Crabo; 1 ♂, Chelan Co., Icicle Creek Canyon 5 mi SW. of Leavenworth, 2 VII 1994, A. and L. Crabo; 1 ♂, [Columbia County], Dayton, 1,620' [494 m], 20 VII 1971, R. E. Miller; 1 ♂, 3 ♀♀, Okanogan County, Goat Wall, 2.1 mi [3.4 km] SE. of Lost River, 48.64°N 120.47°W, 2,480' [756 m], 25 VII 1997, L. Crabo; 4 ♂♂, 1 ♀, Okanogan County, Hart's Pass Rd., 1.5 mi [2.4 km] NW. of Cache Creek, 48.67°N 120.61°W, 4,800' [1,463 m], 24 VII 1997, L. Crabo; 1 ♂, 1 ♀, Okanogan County, Methow R. Valley, Lost River Rd. at Lost R., 48.65°N 120.50°W, 2,390' [728 m], 23-25 VII 1997, E., A., and L. Crabo; **Oregon**: 17 ♂♂, 1 ♀, Wheeler County, Blue Mountains, State Rte. 207 2 mi [3.2 km] W. of Bull Prairie, 44.96°N 119.70°W, 4,400' [1,341 m], 15 VII 1996, E. and L. Crabo; 1 ♂, 15 mi E. of Coquille, 29 VII 1965, K. Goeden; 1 ♀, Newberg, Yamhill Co., 15 VIII 1969, K. Goeden; 1 ♂, 8 mi S. of Enterprise, Wallowa Co., 1 VII 1968, K. Goeden; 2 ♂♂, 2 ♀♀, Eugene, Lane Co., 28 VI 1971, K. Goeden; 1 ♂, Eugene, Lane Co., 16 VIII 1972; 1 ♂, Spring Creek, Baker Co., 13 VII 1970, K. Goeden; 1 ♀, Spring Creek, Baker Co., 17 VII 1972; 1 ♂, 3 mi E. of Lakeview, Lake Co., 20 VI 1976, K. Goeden; 1 ♂, Warm Springs Res. nr. Mt. Jefferson, Jefferson Co., 19 VII 1969; 1 ♂, 5 mi W. of Mill City, N. Fork Santiam R., Hwy 22, Marion Co., 2 VII 1981; 1 ♂, Honey Creek nr. Glide, Douglas Co., 13 VI 1996; 1 ♀, vic. Firewood Rd., 4 mi W. of Oregon City, Clackamas Co., 22 VII 1975, S. G. Jewett Jr.; 1 ♂, vic. Firewood Rd., 4 mi W. of Oregon City, Clackamas Co., 13 VII 1975, S. G. Jewett Jr.; 1 ♂, vic. Bosky Dell Ln., 4 mi W. Oregon City, Clackamas Co., 14 VIII 1981, S. G. Jewett Jr.; 1 ♂, same locality and collector, 29 VII 1978; 1 ♂, Ochoco Mts. nr. summit, Hwy 26, Crook Co., 21 VII 1975, S. G. Jewett Jr.; 1 ♂, Blue Mts., Starkey Exp. For., 10 VII 1996; 1 ♂, North Ward Th., Lane Co., 8 VI 1995; 1 ♂, 1 ♀, same locality, 28 VI 1995; 2 ♂♂, 1 ♀, North Ward Th., nr. Lorane, Lane Co., 29 VI 1995; 1 ♂, Lane Co., 1 mi W. of Rainbow, 27 VI 1997, J. Troubridge; 2 ♂♂, Lane Co., Frissell Pt., 1506 Rd., 1,550 m, 13 VII 1996, J. Troubridge; **British Columbia**: 2 ♀♀, Kirby Flats Rd., ca. 25 km S. of Lillooet, 4 VII 1997, J. Troubridge; 1 ♂, 1 ♀, same locality and collector, 9 VIII 1997; 1 ♂, 5 km W. of Oliver, 30 VI 1996, J. Troubridge; 1 ♂, 1 ♀, Mt. Kobau, 1,200-1,800 m, 1 VIII 1997, J. Troubridge; 3 ♂, 1 ♀, Castlegar (Brilliant), 16 VI 1995, J. Troubridge; 1 ♂, 1 ♀, 5 km SE. of Okanagan Falls, J. Troubridge; 1 ♂, same locality and collector, 1-7 VII 1993; 1 ♂, same locality and collector, 5-10 VII 1990; 1 ♂, same locality and collector, 12-18 VIII 1990; 1 ♂, same locality, 23-31 V 1992, J. Troubridge and M. Gardiner; 2 ♂♂, same locality and collectors, 7-13 VI 1992; 1 ♂, same locality and collectors, 1-6 VI 1992; 1 ♂, same locality and collectors, 12-18 VII; 1 ♂, Lillooet, dunes E. side of Fraser R., 29 VI 1996, J. Troubridge; 3 ♂♂, E. end of Seton Lk., 13 VI 1996, J. Troubridge; 2 ♂♂, same locality and collector, 5 VII 1996; 1 ♂, 1 ♀, same locality and collector, 29 VI 1996; 1 ♂, same locality and collector, 7 VII 1995; 1 ♂, same locality and collector, 17 VII 1995; 1 ♂, same locality and collector, 3 VI 1995; 2 ♂♂, 1 ♀, same locality and collector, 23 VI 1995; 1 ♂, 3 mi [4.8 km] N. of Roosville, 6 VII 1991, J. and S. Shepard; 1♂, Monte Lake, 19 VI 1988, J. Shepard; 1 ♂, Riske Creek, Deer Park Ranch, Moon Road, 2,000' [610 m], Aud I. Fischer.

**Description**. Forewing length 12-14 mm. Antennae filiform, scape gray with black dorsum; head black; palpae very dark gray; prothoracic collar black basally, then light

gray, then slightly darker gray with dark scales with light gray tips; thorax same as adjacent collar; abdomen gray-brown. Dorsal forewing with gray, gray-brown, and scattered black scales, appearing light gray basally and near costa, gray-brown below cell, darker gray-brown towards the outer margin, and dark gray at costal margin; ordinary spots and median and subterminal lines absent; basal, antemedial, and postmedial lines even, black; antemedial line broad and thickened at costa, straight except for a slight angle where joined to the postmedial line by a straight black line across the median space between veins CuA2 and 1A+2A; postmedial line thin, thickened at costa, sinuous, prominently excurved opposite cell and straight posterior to line joining it to antemedial line; four to six smooth black dashes extend to outer margin between veins R4 and R5 to CuA1 and CuA2, that between M1 and M2 darkest and longest, extending from end of cell across postmedial line to margin, the others originate lateral to the postmedial line, the most posterior two lines variably present; fringe concolourous with the margin. Dorsal hindwing whitish-gray, blending to gray-brown toward the margin and costa; postmedial line dark brown; veins dark brown; fringe brown basally, white terminally. Males and females similar except that the dorsal hindwing of the female is darker gray.

**Male genitalia**. Uncus short, equal to valve width. Valve (Figure 3a) 4x as long as wide, widest proximal to clasper and tapered to cucullus beyond clasper, cucullus bluntly pointed at dorsal margin; clasper 2/3x as long as valve width ending well below costa, talon-like, mid-section widened mesially, apical spine directed dorsolaterally. Vesica (Figure 2j) bends gently downward to the right and then curves to the left; a small basal field of spine-like cornuti is located on the left, a large field of dense spine-like cornuti on the middle half of the vesica starts dorsally and forks ventrad to the right and dorsad to the left, vesica apex with small bundle of long ventral cornuti and a stout dorsally-projected cornutus.

**Female genitalia**. Ovipositor lobes rounded, covered with setae; ductus bursae sclerotized; corpus bursae bisaccate with bulbous anterior chamber, tapered toward tip and connected by a long narrow neck to the bean-shaped posterior chamber; appendix bursae arises from posterior chamber and sweeps around 180° to ductus seminalis.

**Derivation of the name**. We name this species in honour of our friend and colleague L. Paul Grey, late of Lincoln, Maine.

**Diagnosis.** *Oncocnemis greyi* is distinguished from the other members of this group by the presence of gray-brown scales of the dorsal forewing, absent in the other species. In addition, the antemedial line is more or less straight (ca. 170°), while in *O. figurata* (Figure 1t) and *O. semicollaris* Smith (Figure 1u), the line forms an angle of about 130°. The antemedial line of *O. ragani* is not as deeply angled as that of *O. figurata* and *O. semicollaris*, and can resemble that of *O. greyi*, but the dorsal hindwing of *O. ragani* is pearlescent white and that of *O. greyi* is gray-brown.

**Distribution and Habitat**. *Oncocnemis greyi* has been found in dry forests from the southern interior of British Columbia, south through central Washington and central Oregon. It occurs sympatrically with *O. semicollaris* at some locations and is usually the more common of the species. Most Pacific Northwest specimens of *O. greyi* have previously been misidentified as *O. semicollaris* in museums.

4. *Oncocnemis saxatilis* **sp. n.**
          (Figures 1f, 2l, 3c)

**Type Locality**. USA, Oregon, Joseph.
**Type material**. Holotype male: Oregon, Joseph, 6 IX 1950, J. L. Sperry, in the CNC. Paratypes: 7 ♂♂: **Washington**: 3 ♂♂, Douglas County, S. end Jameson Lake, 27 IX 1996, J. Troubridge; 1 ♂, Douglas County, S. end Jameson Lake, 23 IX 1996, J. Troubridge; **Oregon**: 2 ♂♂, Crook County, 5 mi S. of Suplee, 7 IX 1962, K. Goeden; 1 ♂, Joseph, 2

IX 1950, J. L. Sperry.

**Description**. Forewing length 13-15 mm. Antennae filiform, scape white; head, palpae, prothoracic collar and thorax with a mixture of black, brown, and white scales that gives an overall gray appearance; abdomen with mixture of white and dark gray scales, appearing gray. Dorsal forewing dark fuscous gray with a grizzled, intricate pattern, nearly white in subterminal space adjacent to reniform; basal dash black; lines except subterminal line black, basal line angled at radial vein, antemedial line prominently undulating, median shade touching reniform spot, then parallel to postmedian line to posterior margin, postmedial line undulating, obsolete across cell, subterminal line white, jagged, preceded by a series of prominent black wedges between veins; spots thin, black, filled with white with brown and dark gray centres; orbicular spot oval, with centre dark gray; reniform spot large, its lateral portion faint so that white filling appears fused to pale adjacent area in subterminal space, central filling mostly light brown; claviform spot large, its central filling mostly brown; fringe dark gray basally, checkered with black and light gray. Dorsal hindwing cream, darker gray basally, with well-defined broad marginal band and a dark gray discal lunule; fringe black basally, white terminally.

**Male genitalia**. Valve (Figure 3c) atypical for genus, 5x as long as wide, widest at clasper where costal margin becomes dorsally convex (straight or concave in most other *Oncocnemis*), tapered beyond clasper to a 0.12 mm long apical spine at ventral cucullus; corona weak; clasper heavily sclerotized, thin, spine-like, 2/3x as long as valve width without reaching costa, located 3/4 of the way from base to apex near proximal cucullus. Aedoeagus (Figure 2l) bent ventrad at midpoint; vesica bent 130° dorsad at base, then straight, equal to aedoeagus in length, with a small right-sided basal diverticulum; a wide ribbon of sparse, spine-like cornuti runs the full length of the ventral vesica; a large patch of dense, long cornuti is positioned centrally on the dorsal surface; a single apical cornutus on the right side extends dorsad.

**Female genitalia**. Unknown.

**Derivation of the name**. The name is from Latin and means "living among rocks". This species occurs in lithosol habitats.

**Diagnosis**. *Oncocnemis saxatilis* is closely related to *O. kelloggii* H. Edwards (HT AMNH [examined]). It is distinguished from *O. kelloggii* (Figure 1g), which occurs in the Sierra Nevada, by its dark gray dorsal forewing, which in *O. kelloggii* is light blue-gray, and by the appearance of the prominent forewing white spot which is transected by the postmedial line in *O. kelloggii* but not in *O. saxatilis*. The dark basal suffusion of the dorsal hindwing of *O. kelloggii* extends to the discal lunule, but falls well short of the discal lunule in *O. saxatilis*. The scales on the thoracic collar of *O. kelloggii* are narrow and hair-like, while those of *O. saxatilis* are narrow basally but fan out towards the apex to become many times wider than their base. Internally, the vesica of *O. saxatilis* has a small basal diverticulum, which is absent in *O. kelloggii* (Figure 2m).

*Oncocnemis saxatilis* resembles *O. sagittata* which is known from Lake County, Oregon, in the Pacific Northwest. In *O. sagittata* the hindwing discal dot is absent from the dorsal side and is punctate ventrally, while that of *O. saxatilis* is prominent, especially on the ventral side.

The shape of the distal valve and the shape and position of the clasper of *O. saxatilis* (Figure 3c) and *O. kelloggii* are unusual for the genus. The higher classification of these species is beyond the scope of this paper.

**Distribution and Habitat**. *Oncocnemis saxatilis* is known from the Columbia Basin at Moses Coulee, Douglas County, Washington, and from eastern Oregon at Suplee, Crook County, and Joseph, Wallowa County. Where known, the habitat is sagebrush steppe with lithosol.

## The *O. tenuifascia* group

Members of the *tenuifascia* group are small (forewing length 10-14 mm), have a mixture of gray, white, and tan scales on the forewing producing a mottled appearance with medium to dark gray or brown ground colour, have a well-defined, scalloped, postmedial line which is black with an adjacent pale area laterally and is prominently laterally convex at the cell, and black discal dot and terminal band of the dorsal hindwing. Three species of this group are found in the Pacific Northwest: *O. tenuifascia* (HT Michigan State University [photograph examined]), *O. parvanigra* Blackmore (HT Canadian National Collection [examined]), and one new species, *O. mus*. *Oncocnemis tenuifascia* occurs in arid sagebrush steppe habitat in mid and late September while *O. mus* is found at mid to high elevation earlier in the year. The easily recognizable *O. parvanigra* is found at high elevations in the Cascade Mountains as far south as Lane County, Oregon, but occurs at lower elevations in southern British Columbia. It has been collected from late July to late September. A key for separating these species by wing markings is presented.

### Key to the adults of the *O. tenuifascia* group

1. Distinct black median line transects discal lunule on ventral hindwing; forewing length 10-11mm . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .2
- Ventral hindwing with distinct black discal lunule, black median line absent; forewing length 12-14mm . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *O. parvanigra*
2. Ground colour of forewing brownish, forewing fringe without checkered pattern. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .*O. mus*
- Ground colour of forewing light to medium gray, forewing fringe distinctly checkered white and dark gray . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . *O. tenuifascia*

5. *Oncocnemis mus* **sp. n.**
        (Figures 1h, 1j, 2d, 3j)

**Type Locality**. USA: Washington, Table Rock, Columbia Co., 46° 01' N 117° 54' W.
**Type material**. Holotype male: Washington, Table Rock, Columbia Co., 46° 01' N 117° 54' W, 1,900 m, 14 VIII 1998, J. Troubridge, in the CNC. Paratypes, 125 ♂♂, 4 ♀: **British Columbia**: 1 ♂, Watch Peak, west of Invermere, 23 VII 1994, J. Troubridge; **Washington**: 114 ♂♂, 1 ♀, same data as holotype; 5 ♂♂, 1 ♀, Table Rock, [Columbia County], 10 VIII 1967, 6,000' [1,850 m], R. E. Miller; 1 ♀, Dayton, 1 IX 1957, 6,500' [2,000 m], R. E. Miller; 2 ♂♂, Oregon Butte, 6,300' [1,920 m], 3 IX 1966, R. E. Miller; **Oregon:** 3 ♂, 1 ♀, Wallowa Co., Blue Mts., 45° 59' N 117° 53' W, 14 VIII 1998, J. Troubridge.
**Description**. Males and females similar. Forewing length 10-11 mm. Antennae filiform, dorsal surface striped black and brown; head, palpae, scape, prothoracic collar, thorax, and abdomen brown. Dorsal forewing mottled brown and gray-brown; lines black, heaviest at costa and trailing margin: basal line laterally convex; antemedial line undulating, edged basally with pale brown; median shade dark gray, diffuse; postmedial line distinct, weakly scalloped, laterally convex portion opposite cell more rounded than in *O. tenuifascia*, edged distally with beige; subterminal line irregular, indistinct, preceded by variable black shading, heaviest near costa, and a series of black chevrons between veins; terminal line scalloped, slightly lighter brown than ground colour, enclosing a series of black spots at margin; spots thin, black, filled with lighter brown than ground colour; claviform incomplete; orbicular elliptical; reniform spot interrupted at top and bottom; orbicular and reniform spots connected by a thin black line; fringe dark brown, weakly checkered with black. Dorsal hindwing beige, dark gray basally, with distinct black discal lunule

transected by black median line; wide marginal band black; fringe gray basally, white distally.

**Male genitalia**. Valve (Figure 3j) 4x as long as wide, widest just beyond clasper, then gently tapered to rounded cucullus; clasper located at mid-valve, 3/4x as long as valve width reaching costa, talon-like, mesial mid-section slightly widened. Vesica (Figure 2d) 2x as long as aedoeagus, sweeps 90° ventrad and then 90° to the left, with a small basal diverticulum on left; a ribbon of cornuti extends from dorsal surface at diverticulum along the right side to the second bend, and then ventrad to the apex, with cornuti becoming longer and denser distally; a ventral patch of long, dense cornuti extends from the second bend to apex; at apex a single, coarse apical cornutus points ventrad and a small bundle of cornuti is projected dorsad.

**Female genitalia**. Ovipositor lobes rounded, covered with setae; a corona of short spines surrounds the ovipositor lobes about 0.1 mm from tip, these spines are produced at 90° to the abdomen; a sclerotized plate occurs on ventral surface of ductus bursae at ostium bursae, ductus bursae otherwise not heavily sclerotized; corpus bursae 2x as long as wide, produced slightly ventrad and to the right at the anterior end which gives rise to ductus seminalis; small appendix bursae (0.05 x 0.2 mm) is located ventrally near ductus bursae.

**Derivation of the name**. The name is from Latin, means mouse, and refers to the small size and brown colour of the adults.

**Diagnosis**. *Oncocnemis mus* is very similar to *O. tenuifascia* and is distinguished from it predominantly by the brown forewing colour in *O. mus*. In addition, there are several subtle differences in maculation. These include: dark scales between the orbicular and reniform spots form a distinct line in *O. mus*, but not in *O. tenuifascia*; the laterally convex portion of the postmedial line is relatively rounded in *O. mus* and more truncate in *O. tenuifascia*; the pale scales lateral to the subterminal line are wider in *O. tenuifascia*, especially in the fold; and the checkering of the fringe is more evident in *O. tenuifascia*.

**Distribution and Habitat**. *Oncocnemis mus* has been collected on dry ridges above 1,500 m in the Blue Mountains of southeastern Washington, and the Purcell Mountains, west of Invermere, British Columbia, at 2,500 m.

6. *Oncocnemis parvacana* **sp. n.**
       (Figures 1a, 2k, 3d)

**Type Locality**. USA, Washington, Benton Co., Hanford Site, sand dunes W. of Columbia R.

**Type material**. Holotype male: Washington, Benton Co., Hanford Site, sand dunes W. of Columbia R., N46°1.369' W119°21.192', 3 IX 1997, L. Crabo and R. S. Zack, in the CNC. Paratypes: 29 ♂♂; 21 ♀♀: **Washington**: 1 ♂, same as type locality, 7 IX 1996, R. S. Zack and D. Strenge; 2 ♂♂, same locality, 27 IX 1996, R. S. Zack, P. McGhee, and C. Nobbs; 7 ♂♂, same locality, 18 IX 1996, R. S. Zack; 1 ♂, 16 ♀♀, same locality, 9 X 1996, R. S. Zack; 4 ♂♂, 30 mi SE. of Quincy, Frenchman Hills, 22 IX, 1960, W. C. Cook; 1 ♀, 5 mi N. of Pasco, 27 IX, 1960, W. C. Cook;  2 ♂♂, 2 ♀♀, Grant County, 1.5 mi N. of Wanapum dam on Hwy 243, 225 m, 22 IX 1990, L. Crabo; 4 ♂♂, 2 ♀♀, Grant County, 2 mi N. of Wanapum dam on Hwy 243, 17 IX 1994, J. Troubridge; 1 ♂, Benton County, Hanford Site, sand dunes W. of Columbia R., N46°31.369' W119° 21.192', 7 Sept, 1996, R. S. Zack and D. Strenge; 1 ♂, same locality, 3 IX 1997, L. Crabo and R. S. Zack; **Oregon**: 8 ♂♂, Biggs, 2 X 1945, E. C. Johnston.

**Description**. Males and females similar. Forewing length 9-11 mm. Antennae filiform, scape white; head and thorax gray with white-tipped scales; palpae white basally, distal second and third segments gray; prothoracic collar gray, thinly edged with white; abdomen gray-brown. Dorsal forewing with gray, white and light gray-brown scales, appearing

mottled medium gray, darkest in median area and toward lateral margin, and light gray-brown in subterminal space; basal line absent; antemedial line absent or weak, dark gray when present; median shade weak, dark gray, visible near costa; postmedial and subterminal lines irregular, dark on veins, evident mainly as light filling, subterminal line preceded by dark gray scales; terminal line scalloped, pale; margin with a series of black dots between the veins; orbicular and reniform spots thin, black, filled with white and light brown and central black spots, orbicular elliptical, reniform spot incomplete; fringe light gray, checkered dark gray between veins. Dorsal hindwing off-white, buff in females, light gray basally, with weak gray discal dot and black, sharply-demarcated terminal band; fringe black basally, white terminally.

**Male genitalia**. Valve (Figure 3d) 3.4x as long as wide, widest slightly beyond clasper, dorsal cucullus a blunt point; clasper 2/3x as long as valve width reaching costa, talon-shaped, mid-section equal to base in width. Vesica (Figure 2k) 2x as long as aedoeagus, with 90° bend dorsad 1/3 of distance from base to apex, then a 180° counterclockwise spiral to end posterior and dorsal to distal aedoeagus; a patch of long, dense, spine-like cornuti is located on the left side of the distal half of the vesica; a ribbon of short, sparse cornuti extends along the right side from the dorsal base to the apex with the cornuti becoming denser and longer distally; a small patch of apical cornuti projects dorsad, and a single, heavy apical cornutus projects to the left.

**Female genitalia**. Ovipositor lobes rounded, covered with setae; a corona of short spines surrounds the ovipositor ca. 0.1 mm from apex, these spines are produced at 90° to the abdomen; ductus bursae short (0.5 mm); corpus bursae stomach-shaped with small, sac-like appendix bursae located dorsally near ductus bursae; anterior portion of corpus bursae forms a cone-like chamber which bends backward on the ventral surface; ductus seminalis arises from the tip of this cone.

**Derivation of the name**. The name is from Latin and refers to the small size and gray colour of this species.

**Diagnosis**. In southern Oregon, *O. satanella* n. sp. (Figure 1b) superficially resembles *O. parvacana*. In *O. parvacana*, the vesica spirals counterclockwise and lacks diverticulae while that of *O. satanella* (Figure 2o) spirals clockwise and has a small dorsal diverticulum. Externally, the dorsal forewing of *O. parvacana* is darker than that of *O. satanella* with the postmedial white line which is present in *O. satanella* reduced or absent. Also, the submarginal black lines between the veins of *O. satanella* are absent or much reduced in *O. parvacana*.

**Distribution and Habitat**. *Oncocnemis parvacana* has been collected in dune habitats along the Columbia River from near Vantage, Washington to the eastern Columbia Gorge at Biggs, Oregon. *Oncocnemis parvacana* is part of an endemic noctuid fauna from this dune system, which also includes *Euxoa hardwicki* Lafontaine, *Copablepharon hopfingeri* Franclemont, and two additional undescribed species of *Copablepharon* Harvey.

7. *Oncocnemis satanella* **sp. n.**
          (Figures 1b, 2o, 3b)

**Type Locality**. USA, Oregon, Malheur Co., Negro Rock Canyon at Sand Hollow.

**Type material**. Holotype male: Oregon, Malheur Co., Negro Rock Canyon at Sand Hollow, 25 IX 1997, J. Troubridge and L. Crabo, in the CNC. Paratypes: 15 ♂♂, 4 ♀♀: **Oregon**: 4 ♂♂, Malheur Co., 12 mi S. of Vale, K. J. Goeden, 2 X 1970; 2 ♂♂, 4 ♀♀, same data as holotype; 4 ♂♂, Sand Hollow, 800 m. 43° 48' N 117° 22' W, 27 IX 1998, J. Troubridge; 1 ♂, Lake County, dunes 2 mi N. of Alkali Lk., 6 IX 1997, J. Troubridge; 3 ♂ ♂, same locality and collector, 14 IX 1998. **Wyoming**: 1 ♂, 7 mi NE. of Lyman, 6,400' [1,970 m], 24 VIII 1964, D. F. Hardwick.

**Description**. Males and females similar. Forewing length 11-12 mm. Antennae filiform, dorsal surface with alternating rows of white and black scales, scape white; head and thorax covered with white-tipped dark gray scales, appearing gray with faint dark and white bands on prothoracic collar; palpae white basally, gray distally; abdomen gray. Dorsal forewing with a mixture of gray, dark gray, white, and beige scales, appearing mottled, medium gray, lighter gray with luteous tint in postmedial space; basal line thin, black; antemedial line undulating, dark gray, double, filled with lighter gray and light-brown gray, postmedial band scalloped, double, dark gray, outer line indistinct, filled with white; subterminal line white, irregular, incomplete, evident between veins and preceded by a series of black wedges in cells R4, R5, M1, M2, M3, CuA1, and CuA2; terminal line scalloped, faint, luteous, followed by terminal black chevrons between veins; median shade faint, dark gray; orbicular spot ovoid, black, filled with white and a prominent central black spot; reniform spot incomplete, double, black, inner portion thickest posteromedially, filled with white between lines and in centre; claviform spot small, black; fringe light gray, checkered with black between veins. Dorsal hindwing off-white, light gray basally, with faint gray discal dot and sharply demarcated, wide black terminal band; fringe black basally, white terminally.

**Male genitalia**. Valve (Figure 3b) 4.3x as long as wide, widest in middle slightly beyond clasper, dorsal cucullus forms a blunt point; clasper 3/4x as long as valve width reaching costa, talon-like, medial mid-section widened. Vesica (Figure 2o) 1.3x as long as aedoeagus, projects ventrad from aedoeagus and spirals gently clockwise, with a tiny ventral and a larger, bump-like right-sided subbasal diverticula; sparse cornuti extend from the dorsal base to cover the larger of the subbasal diverticula; a patch of long, dense, spine-like cornuti is present on the distal half of the ventral vesica; a patch of dense cornuti is present on the dorsal distal half of the vesica; ventral apex with a short, stout cornutus and a bundle of long, thin cornuti.

**Female genitalia**. Ovipositor lobes rounded, covered with setae; a corona of short spines surrounds the ovipositor ca. 0.1 mm from apex, these spines are produced at 90° to the abdomen; ductus bursae has small, circular diverticulum on ventral surface from which ductus seminalis arises; elongate, deeply furrowed appendix bursae (ca. 1/3x as long as corpus bursae) arises from right side of corpus bursae.

**Derivation of the name**. The type locality is hot, dry, desolate, and home to the greatest concentration and diversity of venomous creatures that we have ever experienced, thus the name, from Greek, which means "little Satan".

**Diagnosis**. The most closely related species is *O. balteata* Smith (HT American Museum of Natural History [examined]) (Figure 1c), a Great Plains species not known to occur in the Pacific Northwest. *Oncocnemis satanella* is separated from it by its gray thorax, which is reddish brown in *O. balteata*, the orange-brown colour of the submarginal area of the dorsal forewing of *O. balteata*, which is gray in *O. satanella*, and the black streaks between the veins on the distal forewing of *O. satanella*, which are absent in *O. balteata*. In eastern Oregon, *O. satanella* superficially resembles *O. parvacana*, which occurs further to the north in the Columbia Basin. They are distinguished from each other by the characters given under *O. parvacana*, above.

**Distribution and Habitat**. *Oncocnemis satanella* is known only from the two localities in the Basin and Range province of southeastern Oregon and a single locality in southwestern Wyoming (west of the Continental Divide). Both of the Oregon localities are in habitats with sandy soil. The Wyoming habitat is unknown.

8. *Oncocnemis tartarea* **sp. n.**
        (Figures 1l, 2a, 3g)

**Type Locality**. USA, Oregon, Malheur Co., Negro Rock Canyon at Sand Hollow.

**Type material**. Holotype female: Oregon, Malheur Co., Negro Rock Canyon at Sand Hollow, 25 IX 1997, J. Troubridge and L. Crabo, in the CNC. Paratypes: 2 ♂♂: **Oregon**: Malheur Co., 12 mi SW. of Vale, 2 X 1970, K. Goeden.

**Description**. Males and females similar. Forewing length 13.5-14 mm. Antennae filiform, scape white; palpae white with a few gray scales on lateral first and second segments; frons white, top of head white with a few fawn scales; prothoracic collar weakly striated, white thinly edged with brown basally, then fawn, white, brown, and white; thorax off-white with occasional fawn and black scales, a weak fawn dorsal tuft at junction with abdomen; abdomen off-white with scattered gray scales. Dorsal forewing with white, light yellow-brown, fawn, brown-gray, and black scales, appearing hoary gray-brown, darkest at apex in subterminal space, with lighter off-white areas basad to antemedial line, posterior to the orbicular spot in the median area, in the postmedial space between posterior margin and CuA1 and anterior to M2, and at anal angle in subterminal space; veins lateral to postmedial line black, veins medial to postmedial line ground colour, not pale; basal line thin, black; antemedial and postmedial lines thin, black: antemedial line zigzag, oriented perpendicular to posterior margin; postmedial line scalloped, laterally convex from costa to fold, then nearly straight to posterior margin, followed laterally by a thin white line; median shade dark gray, strongest at costa; postmedial line irregular, light gray, preceded by dark gray wedges between veins; terminal line even, black; claviform, orbicular and reniform spots dark gray, filled with white with pale fawn centres: orbicular spot ovoid; reniform spot quadrate, widest posteriorly; claviform elongate, nearly reaching subterminal line; fringe white basally, dark gray terminally. Dorsal hindwing off-white with scattered gray scales basally along cubitus; subterminal line thin, incomplete, evident mostly at veins; terminal band wide, sharply demarcated, black; fringe immaculate white.

**Male genitalia**. Valve (Figure 3g) 3.7x as long as wide, widest at clasper with a slight constriction at base of cucullus, cucullus projects dorsad and is rounded; clasper 4/5x as long as valve width, extending to costa, mid-section slightly widened. Vesica (Figure 2a) bends gently to the right at base and then sweeps ventrad and to the left; a small patch of sparse, short cornuti extends from the base to mid vesica on dorsal surface; a dense patch of long cornuti extends from mid vesica to the apex on the right; a dense patch of medium-length cornuti extends from the left mid vesica to the dorsal apex; apically, a spine-like cornutus is directed posteriorly and a bundle of long cornuti is directed ventrad.

**Female genitalia**. Ovipositor lobes rounded, covered with setae; a corona of short spines surrounds the ovipositor ca. 0.1 mm from apex, these spines are produced at 90° to the abdomen; ductus bursae short and broad (0.8 x 0.8 mm) with sclerotized ventral plate; corpus bursae unisaccate, stomach-shaped, its anterior portion forms a cone-like chamber which bends posteriorly to the right to join ductus seminalis at the tip.

**Derivation of the name**. This species is known only from the type locality and was collected with *O. satanella*, above. We feel that the name, which is from Latin and roughly means "of the lower level of Hades", refers appropriately to the type locality.

**Diagnosis**. *Oncocnemis tartarea* is a member of the *O. levis* Grote group, which is characterized by the distally tapered and rounded male valve. Members of this group are gray-brown or brown with well-defined dorsal forewing markings, and a dark terminal band on the dorsal hindwing. The adults are found in steppe habitats in the fall during the flowering of rabbitbrush (*Crysothamnos nauseosus* (Pall.)). *Oncocnemis tartarea, O. levis* (Figure 1m), *O. simplex* and *O. sanina* Smith (Figure 1k) are the members of this group that are known from the Pacific Northwest. Internally, *O. tartarea* can be separated from

*O. levis* by the vesica, which is produced at a 90° angle to the right in *O. levis*, gently to the right and then downward to the left in *O. tartarea*, and by the valve, which is narrowed in the distal half in *O. levis* but only in the distal quarter or third in *O. tartarea*. Externally, *O. tartarea* is paler coloured than the other Pacific Northwest species. It lacks pale scales along the veins and dark spots in the subterminal area which are present in the other species. It is most similar to *O. sanina* (Figure 1k) which also has an off-white hindwing, but can be separated from it the dark brown forewing and forewing fringe colour, lighter whitish in *O. tartarea*, and the characteristic elongate elliptical orbicular spot of *O. sanina*. *Oncocnemis iricolor* Smith, which occurs with *O. tartarea* at the type locality, is also similar to it and has a pure white hindwing fringe. It can be separated from *O. tartarea* by the presence of charcoal gray patches in the subterminal space of the dorsal forewing.

**Distribution and habitat**. *Oncocnemis tartarea* is known only from the type locality, in the sagebrush desert of eastern Oregon. The site is situated in the Snake River drainage on sandy soil. It has been collected in late September and early October.

### 9. *Oncocnemis goedeni* **sp. n.**
       (Figures 1s, 2f, 3h)

**Type Locality**. USA, Oregon, Jackson County, Medford.

**Type material**. Holotype male: Oregon, Jackson Co., Medford, 28 VIII 1970, K. J. Goeden, in OSU. Paratypes: 9 ♂♂, 5 ♀♀: **Oregon**: 4 ♂♂, same data as holotype; 1 ♂, same locality and collector, 26 VIII 1969; 1 ♂, same locality and collector, 27 VIII 1970; 1 ♂, same locality and collector, 10 IX 1965; 1 ♂, same locality and collector, 30 VIII 1969; 1 ♂, same locality and collector, 23 VIII 1970; 1 ♀, Grants Pass, Josephine Co., 6 IX 1968, K. Goeden; 1 ♀, same locality and collector, 10 IX 1968; **California**: 1 ♀, La Tuna Cyn., Los Angeles Co., 23 IX 1949, W. H. Evans; 1 ♀, same locality and collector, 21 IX 1949; 1 ♀, W. Fork San Gabriel Cyn., 1,600', Los Angeles Co., 29 X 1965.

**Description**. Forewing length 16-17 mm. Antennae filiform; head, scape, prothoracic collar, thorax, and dorsal forewing light brown; abdomen slightly lighter brown. Dorsal forewing lines and spots dark brown, filled with ground colour; basal, antemedial, and postmedial lines double, these and the median shade widest at costa; antemedial line undulating, oblique, closer to base at costa than at posterior margin; median shade and scalloped postmedial line laterally convex at cell; postmedial line irregular, indistinct, evident due to proximal dark shade; orbicular elliptical; reniform relatively wide; claviform short; fringe brown. Dorsal hindwing white in the male, light brown in the female, darker at costa and medial margin; veins and relatively narrow terminal band light brown; fringe off-white, with a narrow light brown line at base.

**Male genitalia**. Valve (Figure 3h) nearly straight, turned slightly dorsad at neck of cucullus, 4.5x as long as wide, widest between clasper and cucullus where posterior margin is thickened, cucullus rounded; clasper 3/4x as long as valve width without reaching costa, talon-like, base narrow and mid-section widened mesially. Vesica (Figure 2f) 2x as long as aedoeagus, bent 90° ventrad at base, slightly to the left at mid-length, and then slightly to the right and ventrad, with a small basal diverticulum on the left; a ribbon of long cornuti extends on ventral surface from the diverticulum to the apex; a patch of dense cornuti is present on the left at mid-vesica; a bundle of ca. seven apical cornuti, as long as the aedoeagus, extend posteroventrally beyond apex.

**Female genitalia**. Ovipositor lobes rounded, covered with setae; ductus bursae very long (3 mm) and narrow (0.5 mm); corpus bursae large (7.0 x 2.0 mm); appendix bursae large (3.0 x 1.5 mm), furrowed, bulbous, connected dorsally to the corpus bursae via a short, narrow neck; ductus seminalis arises from the anterior corpus bursae.

**Derivation of the name**. We take pleasure in naming this species in honour of Mr. Ken

Goeden, who collected all of the known Pacific Northwest specimens.

**Diagnosis**. The brown forewing with faintly outlined spots and white hindwing with brown marginal band are characteristic of *O. goedeni*. Two other Pacific Northwest *Oncocnemis* species, *O. phairi* McDunnough and *O. glennyi* Grote, have relatively uniform brown forewing colour; however, the basal area of the dorsal hindwing of these species are light brown, not white as in male *O. goedeni*, and their dorsal forewings are less heavily marked than that of *O. goedeni*. Several *Euxoa* Hübner species, including *Euxoa terrena,* are superficially similar to *O. goedeni* but are easily separated from it by generic characters, including the lack of a foretibial spine. *Lepipolys behrensi* (Grote), a species from southwestern United States not known from the Pacific Northwest, is also similar (including the light two-toned hindwing). Its forewing scales are unusual in that they are broadly triangular so that the forewing resembles a shake roof when magnified, while those of *O. goedeni* are typically shaped.

**Distribution and Habitat**. In Oregon *O. goedeni* is known from two sites in the Siskiyou Mountains: Grant's Pass and Medford. The exact habitat is unknown as these areas have a number of different biotopes, including oak prairie, riparian areas along the Rogue River, dry, mixed deciduous and coniferous forests, and serpentine barrens.

**Revised Pacific Northwest *Oncocnemis*.**

1. *Oncocnemis major* Grote **stat. rev.**
      (Figures 1n, 2i, 3f)

*Oncocnemis major* Grote, 1881: p. 33; Hampson, 1906: p. 175; Barnes and McDunnough, 1917: p. 57; McDunnough, 1938: p. 80.
*Oncocnemis riparia major*, McDunnough, 1941: p. 172; Hodges *et al.*, 1983: p. 147.

**Type Locality**. Colorado.
**Type material**. Lectotype male, in the United States National Museum [examined]. The type is labelled [*Oncocnemis major* Grote Type; Lectotype *Oncocnemis major* Grote by R. W. Poole; Col. [Colorado]; Type No. 33862 U.S.N.M.; Genitalia Slide By USNM 37658]. This specimen is worn and lacks the abdomen and one antenna.
**Diagnosis**. *Oncocnemis major* can be separated from *O. riparia* by the claviform spot, which in *O. riparia* is usually filled with white scales and in *O. major* is gray and indistinct, and by the black streaks surrounded by white scales in the submargin of the dorsal forewing of *O. riparia*, which are absent in *O. major*. Internally, the clasper of *O. major* is wider than that of *O. riparia*, and the distal end of the valve of *O. riparia* forms the widest part of the valve, while that of *O. major* is usually widest at mid-section.
**Distribution and Habitat**. *Oncocnemis major* is widely distributed in the Pacific Northwest, but is uncommon. In British Columbia, *O. major* has been found in arid areas of the Fraser and Okanagan River basins. In Washington, it has been found near Mazama in Okanogan County, near Brewster in Douglas County, and in the foothills of the Blue Mountains. In Oregon, it has been found in arid habitats along the John Day River in the east-central portion of the state and near Klamath Falls in the south. In British Columbia, it is usually collected in association with dense stands of *Penstemon fruticosus* (Pursh), which might be its foodplant.
**Remarks**. Our investigation of *O. riparia* has shown that several similar species are currently placed under this taxon. A revision of the entire species complex is beyond the scope of this paper; however, we recognize *O. major* Grote as distinct from *O. riparia* (HT Michigan State University [examined]). *Oncocnemis riparia* occurs in eastern North America and is associated with sand dunes and beaches.

2. *Oncocnemis extremis* Smith **stat. rev.**
          (Figures 1o, 2b, 3i)

*Oncocnemis extremis* Smith, 1890: 30; Smith, 1893: p.160; Dyar, 1902: p. 124; Hampson, 1906: p. 168; Barnes and McDunnough, 1917: p. 56; Blackmore, 1927: p. 23.
*Oncocnemis chorda extremis* Smith; McDunnough, 1938: 80; Jones, 1951: 69; Hodges *et al.,* 1983: 147.

**Type Locality**. "N. W. British Columbia". The holotype was collected along the railroad, probably in the Thompson or Fraser River canyons between Kamloops and Lytton.
**Diagnosis**. *Oncocnemis extremis* can be separated from the closely related *O. chorda* (Grote) (Figure 1p) by the median shade of the dorsal forewing, which in *O. chorda* is weak below the costa and approaches the antemedial line only at the posterior margin, while that of *O. extremis* is wide, prominent at posterior margin, and fused to the antemedial line in proximity to the cubital vein and at the posterior margin. The dorsal forewing of *O. extremis* is much more heavily suffused with black than that of *O. chorda* and has a less regular postmedial line and a darker distal area. Internally, the vesica of *O. chorda* (Figure 2c) bends ventrad and to the left, while that of *O. extremis* (Figure 2b) is nearly straight beyond its basal bend. Differences between the valves are subtle. In *O. extremis*, the width of the valve is more or less uniform (Figure 3i), while that of *O. chorda* is slightly narrowed at the base.
**Distribution and Habitat**. In British Columbia, *O. extremis* has been found at low to mid elevations, in arid areas around Lillooet, Osoyoos, and the Kootenays. In Washington and Oregon, it occurs on dry ridges in the Cascades to ca. 2,500 m. It is associated with *Penstemon* species, particularly *P. fruticosus,* which might be its foodplant.
          *Oncocnemis chorda* is found at low and mid elevations as far north as Yakima County, Washington and is less common than *O. extremis.* It is most often found in habitats with basalt cliffs. *Oncocnemis extremis* and *O. chorda* are sympatric at Bethel Ridge, Yakima County, Washington, where *O. extremis* appears earlier in the season than *O. chorda,* although both species fly together until early September.

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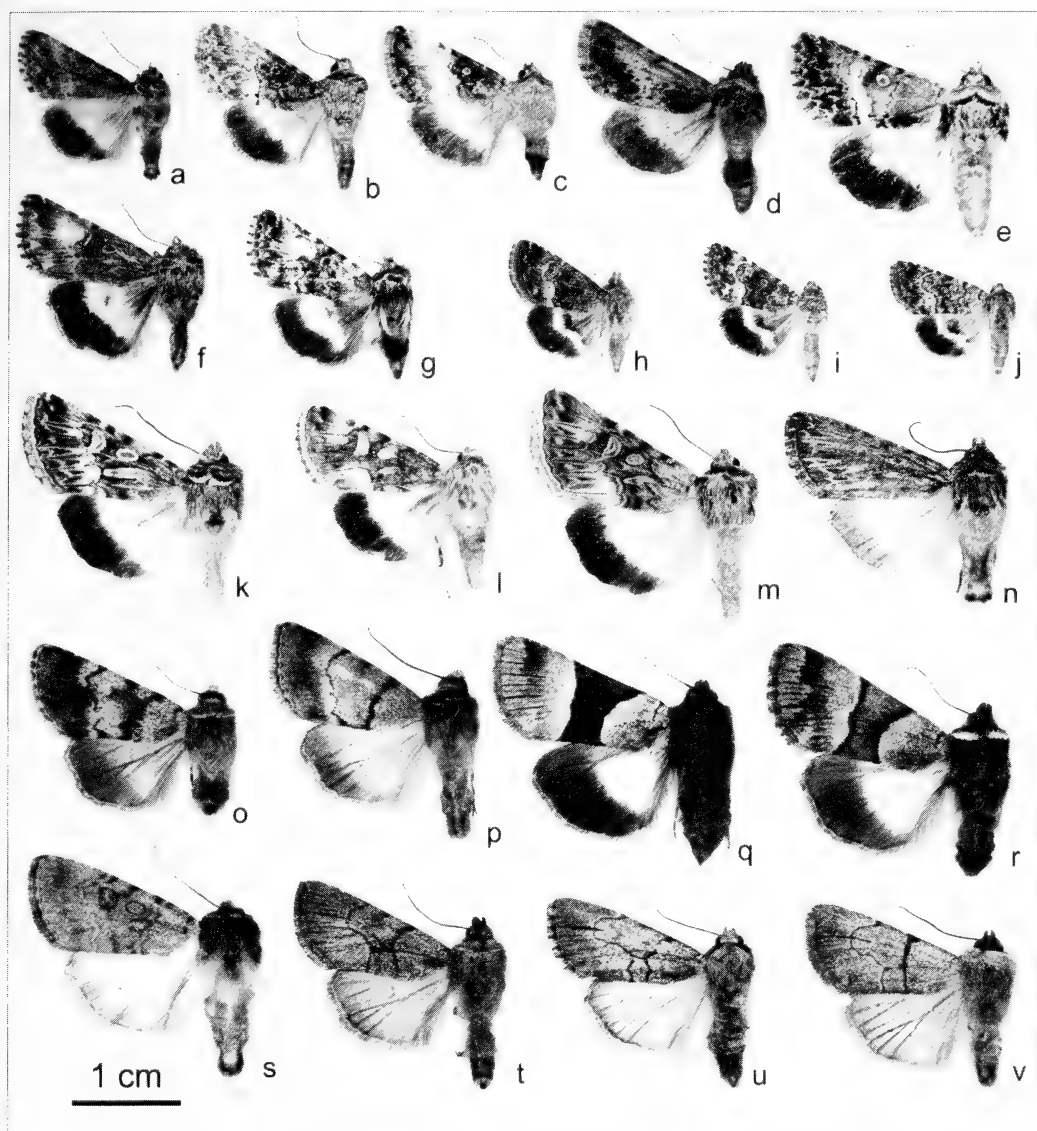
**Figure 1.** Photographs of adults of the genus *Oncocnemis* Lederer. **a)** *O. parvacana* ♂; **b)** *O. satanella* ♂; **c)** *O. balteata* ♀; **d)** *O. coprocolor* ♂; **e)** *O. terminalis* ♀; **f)** *O. saxatilis* ♂; **g)** *O. kelloggii* ♀; **h)** *O. mus* ♂ (Watch Peak, British Columbia); **i)** *O. tenuifascia* ♀; **j)** *O. mus* ♂ (Table Rock, Washington); **k)** *O. sanina* ♂; **l)** *O. tartarea* ♂; **m)** *O. levis* ♂; **n)** *O. major* ♂; **o)** *O. extremis* ♀; **p)** *O. chorda* ♂; **q)** *O. piffardi* ♀; **r)** *O. chalybdis* ♀; **s)** *O. goedeni* ♀; **t)** *O. figurata* ♂; **u)** *O. semicollaris* ♀; **v)** *O. greyi* ♂.
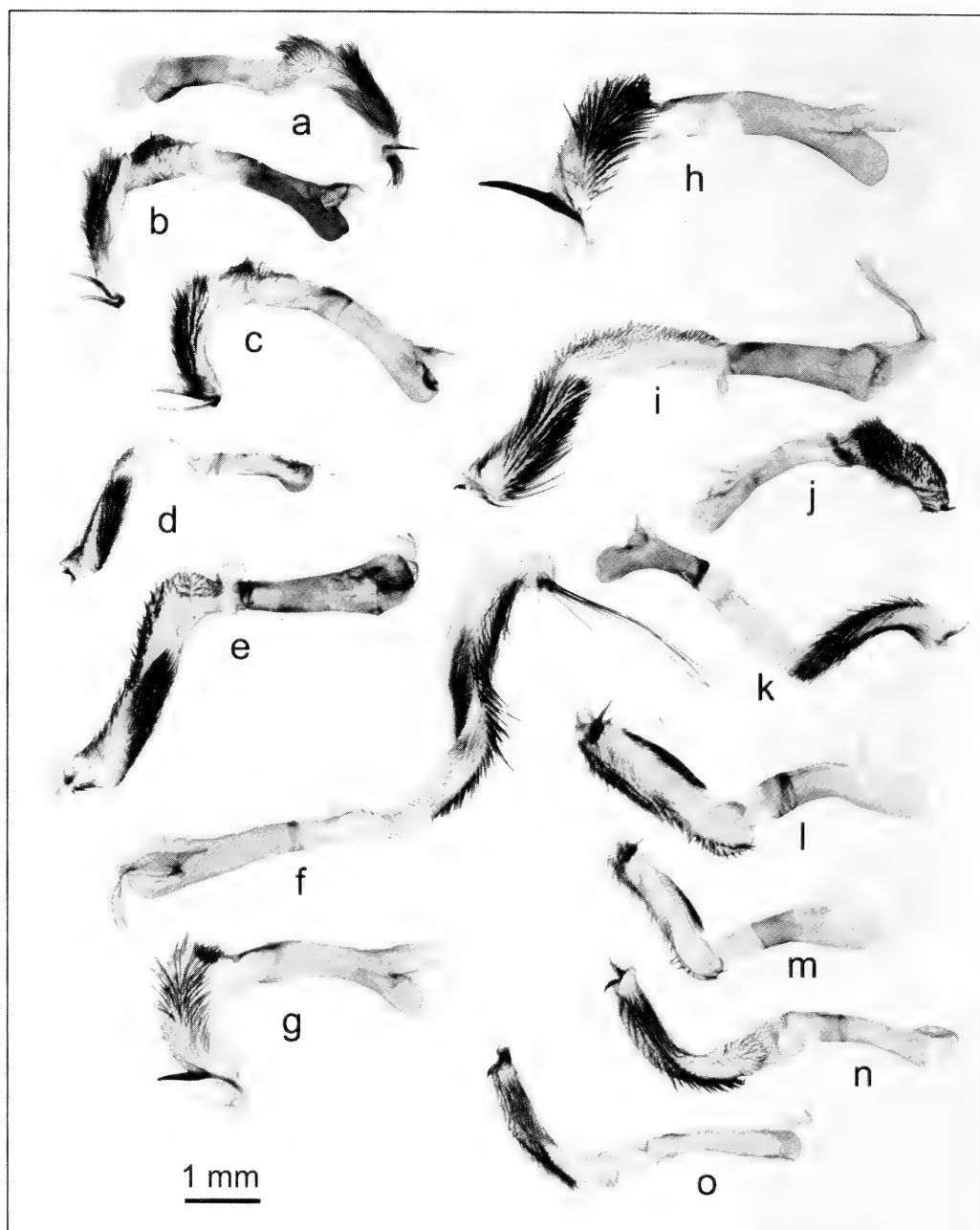
**Figure 2.** Aedoeagae of male *Oncocnemis* species with vesicas everted: **a)** *O. tartarea*; **b)** *O. extremis*; **c)** *O. chorda*; **d)** *O. mus*; **e)** *O. coprocolor;* **f)** *O. goedeni*; **g)** *O. piffardi*; **h)** *O. chalybdis*; **i)** *O. major*; **j)** *O. greyi*; **k)** *O. parvacana*; **l)** *O. saxatilis*; **m)** *O. kelloggii*; **n)** *O. balteata*; **o)** *O. satanella*.
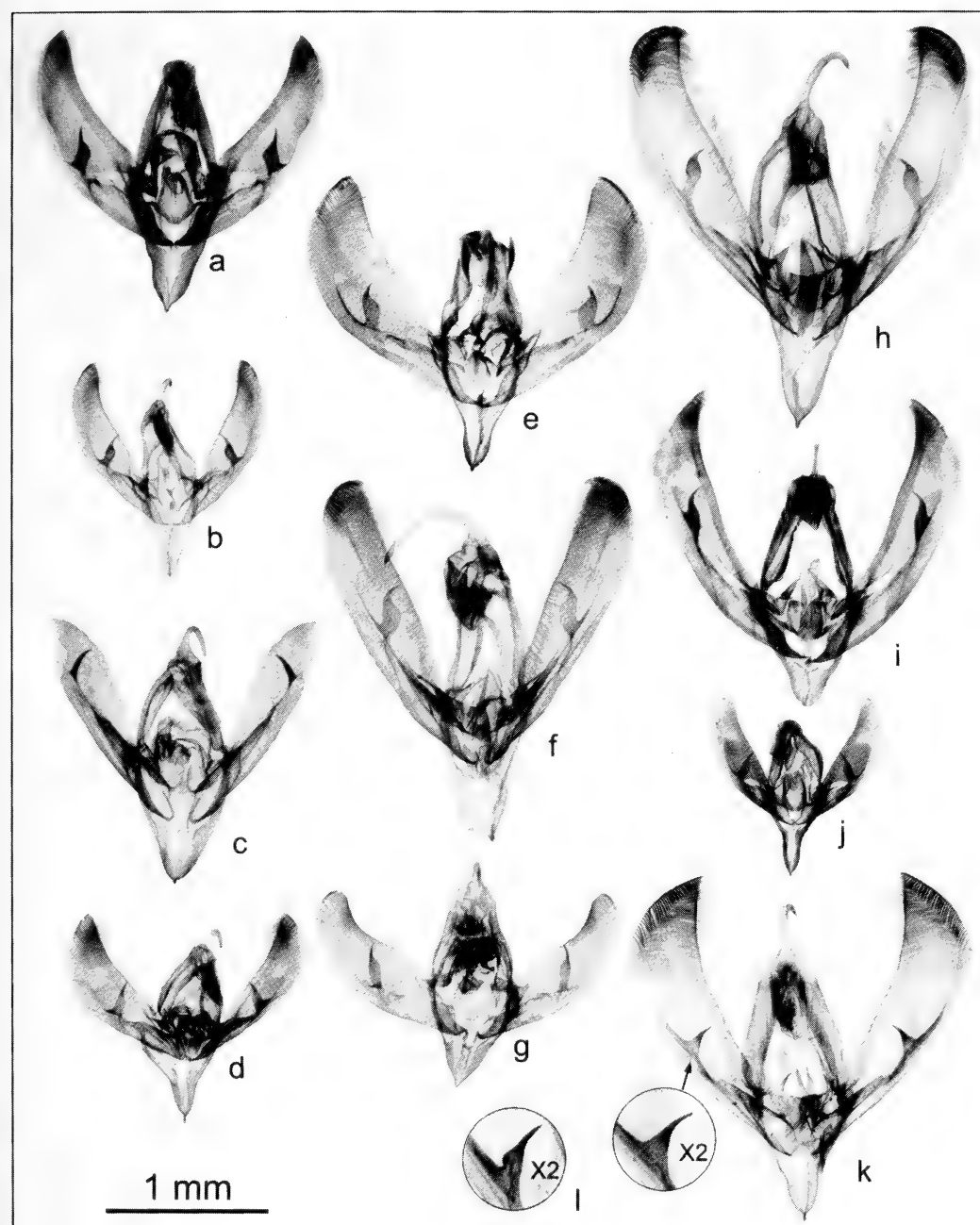
**Figure 3.** Genitalia of male *Oncocnemis* species with aedoeagae removed: **a)** *O. greyi*; **b)** *O. satanella*; **c)** *O. saxatilis*; **d)** *O. parvacana*; **e)** *O. coprocolor*; **f)** *O. major*; **g)** *O. tartarea*; **h)** *O. goedeni*; **i)** *O. extremis*; **j)** *O. mus*; **k)** *O. chalybdis*; **l)** clasper of *O. piffardi*.

# Parasitism of *Lygus* spp. (Hemiptera: Miridae) by *Peristenus* (Hymenoptera: Braconidae) in the Pacific Northwest

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## ABSTRACT

Fourth- and fifth-instar lygus bug nymphs (*Lygus* spp.) were collected from different plants from May through the first week of October in Washington in 1996 and 1997. In 1997, nymphs were also collected from alfalfa seed fields near Ontario, Oregon and Parma, Idaho. Nymphs were dissected under a binocular microscope and the number of nymphs parasitized by a *Peristenus* larva recorded. In 1996 and 1997, *Peristenus* was found in all areas of WA sampled (parasitism rate 32% and 14% respectively) and at Parma, ID but not near Ontario, OR. The *Peristenus* found in Pacific Northwest lygus bugs is apparently a new species, as yet undescribed.

**Key words:** *Peristenus*, *Lygus*, parasites, biological control

## INTRODUCTION

Lygus bugs (*Lygus* spp.) are serious pests of alfalfa and vegetable seeds, apples, peaches and other crops in the Pacific Northwest. The problem has been increased by insecticide resistant *Lygus* populations in several areas (Xu and Brindley 1994). There is little published information on parasites attacking lygus in the Pacific Northwest.

*Peristenus* spp. wasps are known to oviposit in the $1^{st}$-, $2^{nd}$-, and $3^{rd}$-instar nymphs of mirids (Lim and Stewart 1976). The Braconid larva feeds internally, primarily in the abdomen of the lygus nymph. The adverse effects of its feeding are not immediately fatal to the bug. Final-instar parasite larvae emerge from the $5^{th}$-instar nymph or adult of the host and spin cocoons in soil debris (Brindley 1939).

Clancy and Pierce (1966) reported *Peristenus pallipes* Curtis from *Lygus* spp. in Idaho. About 5% of 1,851 of the *Lygus* collected in Utah and southern Idaho alfalfa fields in June 1963 were parasitized by *P. pallipes*. Musebeck *et al.* (1951) also reported *P. pallipes* from *Lygus* spp. in Idaho. The *P. pallipes* from Idaho may be misidentified in light of new work on *Peristenus* taxonomy. There have been no reports of *Peristenus* being found in Oregon or Washington. *Peristenus wallisi* Foerster has been reported from British Columbia (Loan 1974).

European *Peristenus* have been introduced on the eastern seaboard and have had a substantial impact on lygus populations in the East (Day 1996). We feel these introductions should not be made in the Pacific Northwest until the identity and biology of native species is determined. Here we report results of initial surveys and studies to determine the status of *Peristenus* infesting

lygus in the Pacific Northwest.

## MATERIALS AND METHODS

In early October 1995, we collected $5^{th}$-instar lygus bug nymphs from an alfalfa hay field near Prosser, WA for rearing experiments and found several that contained a parasite. On 9 October, we collected several hundred $5^{th}$-instar nymphs from the same field. Fifty-five lygus nymphs from this collection were placed in individual plastic Petri dishes containing cotton soaked in 50 vol/vol sugar syrup and held in the laboratory. After the parasites emerged and pupated, each cocoon was put in a separate gelatin capsule until adult emergence. Also, seventy-five nymphs from this collection were dissected under a binocular microscope.

In 1996 (83 collections) and 1997 (100 collections), $4^{th}$- and $5^{th}$-instar lygus bug nymphs were collected from alfalfa (*Medicago sativa* L.) hay, seed, and waste land, carrot (*Daucus carota* L.), white clover (*Trifolium repens* L.), hoary cress (*Cardaria draba* (L.) Desv.) mint (*Mentha piperita* L.) and pepperweed (*Lepidium campestre* (L.) R.Br.) using a sweep net. Collections were made from May through the first week of October in the Touchet Valley, lower Yakima Valley, upper Yakima Valley and the Columbia Basin of WA. In addition, in 1997 12 samples of adult lygus were collected from the upper Yakima Valley. In 1997, lygus bug nymphs were also collected from alfalfa seed fields near Ontario, OR in June. In 1996 and 1997, we sampled an experimental alfalfa seed field weekly at Prosser, WA and in 1997 a seed field near Parma, ID. In both alfalfa seed fields, lygus were abundant all season and no insecticides were applied in 1996 or 1997.

For each sample in WA, a minimum of 30, $4^{th}$- or $5^{th}$-instar nymphs or adults in 1996 and 1997 were swept from the plants and the bugs put in a vial with Kahle's fixative (Martin 1977). The vials were stored in the laboratory. During the winter, 30 bugs from each sample were dissected under a binocular microscope and the number of nymphs parasitized by a *Peristenus* larva was recorded. In ID, $4^{th}$- and $5^{th}$-instar nymphs were aspirated from a sweep net and frozen. Seven samples of 50 nymphs were taken during the summer and were dissected under a microscope and examined for *Peristenus* parasitism. Duplicate samples of Idaho nymphs were sent alive by overnight Federal Express to W.H Day, United States Department of Agriculture Beneficial Insects Laboratory, Newark, Delaware for rearing and identification.

## RESULTS AND DISCUSSION

All 18 adult *Peristenus* that emerged from WA in 1995 were sent to P.M. Marsh, retired Research Entomologist, who determined them to be *Peristenus* sp. probably *pallipes* although these specimens were not compared with specimens at the United States National Museum Collection. The adult *Peristenus* from ID in 1997 (*N*=30) were examined by W.H. Day, USDA and S. Shaw, University of Wyoming and were determined to be a new species as yet undescribed (Personal Communication). In addition, hundreds of lygus nymphs from ID have been sent to W. H. Day and have been reared for parasite emergence.

In 1995, during the 7 days after the lygus were put into Petri dishes, parasite larvae emerged from 18 of the nymphs, a parasitism rate of 32.7%. All were sent for identification. Of the 75 $5^{th}$-instar nymphs from this collection dissected under a binocular microscope, 25 contained a parasite larva in various stages of development, a 33% parasitism rate.

In 1996 and 1997, *Peristenus* was found in all areas of WA sampled and at Parma, ID but not near Ontario, OR (Table 1). The percent of the samples with at least one parasitized lygus bug was highest in the Upper Yakima Valley although the mean percentage parasitism of those samples between areas was not significantly different. More extensive sampling in ID and OR in 1998 may reveal more widespread lygus parasitism than is currently known.

*Peristenus* was collected from lygus bugs feeding on all the plants sampled with the exception of carrot and mint of which only a few samples were collected (Table 2). The percent of the samples with at least one parasitized lygus bug was highest from hoary cress though the mean percent parasitism of those samples was not very different between the plant hosts.

### Table 1

The number of lygus bug nymph samples by area, the percent of samples with at least one nymph parasitized by *Peristenus* and the mean and range of percent parasitism in those collections. WA, OR 1996-97.

| Location | # of samples | % of samples with *Peristenus* | Mean % (range) of parasitism |
|---|---|---|---|
| Touchet Valley, WA | 65 | 36.6 | 30.7  (2.6-80) |
| Lower Yakima Valley, WA | 59 | 33.9 | 14.4  (2.9-55.3) |
| Upper Yakima Valley, WA | 22 | 70.1 | 23.6  (3.4-41.5) |
| Columbia Basin, WA | 35 | 28.1 | 17.3  (2.2-53.5) |
| Ontario, OR | 4 | 0 | 0 |

### Table 2

The number of lygus bug nymph samples by plant host, the percent of samples with at least one nymph parasitized by *Peristenus* and the mean and range of percent parasitism in those collections. WA 1996-97.

| Plant | # of samples | % of samples with *Peristenus* | Mean % (range) of parasitism |
|---|---|---|---|
| Alfalfa hay | 57 | 24.6 | 15.7  (2.9-43.8) |
| Alfalfa seed | 40 | 30.0 | 23.4  (2.2-69.8) |
| Alfalfa wild | 22 | 63.6 | 30.1  (8.0-63.6) |
| Carrot | 1 | 0 | 0 |
| Clover | 3 | 33.3 | 3.4 |
| Hoary Cress | 8 | 37.5 | 32.3  (8.1-80) |
| Mint | 2 | 0 | 0 |
| Pepper Weed | 8 | 75 | 32.7  (3.1-62.1) |

*Peristenus* larvae were found from May through the first week of October in WA and from July through October in ID (Table 3). It is difficult to determine from the data if a population peak occurred, although the preliminary data suggest a peak in July. In the alfalfa field in WA sampled weekly, *Peristenus* were found from 17-23 June through the first week of October and the highest percent parasitism was found during mid-July and again in mid-August (Table 4). In ID, weekly sampling was begun in early July and the highest percent parasitism was noted on 2 July and again in late August.

In 1996, 41% of the samples collected in WA had at least one parasitized lygus nymph and the parasitism rate of those samples with at least one parasitized nymph was 32%. In 1997, 36% of the samples collected in WA had at least one parasitized lygus nymph and the parasitism rate of those samples with at least one parasitized nymph was 14%. In 1997, a total of 360 adult lygus were dissected and no *Peristenus* larvae were found.

**Table 3**

The number of lygus bug nymphs sampled in different months and the mean percent and range of percent parasitism by *Peristenus*. WA and ID 1996-97.

| | | Washington | | | Idaho | |
| | | 1996 | | 1997 | | 1997 |
| Month | *n* | % Parasitized | *n* | % Parasitized | *n* | % Parasitized |
|---|---|---|---|---|---|---|
| May | 90 | 0 | 360 | 3.0 | -- | -- |
| June | 270 | 10.4 | 600 | 4.3 | -- | -- |
| July | 840 | 28.7 | 1,230 | 6.8 | 150 | 30.6 |
| August | 840 | 3.1 | 270 | 0.4 | 100 | 20.0 |
| September | 360 | 1.3 | 270 | 2.4 | 50 | 34.0 |
| October | 90 | 2.2 | 270 | 0.6 | 50 | 14.0 |

**Table 4**

The percentage of nymphs parasitized by *Peristenus* in samples from the same field on different dates. Field #1 at Prosser, WA and #2 at Parma, ID 1996-97.

| Collection Period | Field #1 | | Field #2 |
| | 1996 | 1997 | 1997 |
|---|---|---|---|
| May 20-26 | 0 | 0 | -- |
| May 27-2 | 0 | 0 | -- |
| Jun 3-9 | 0 | 0 | -- |
| Jun 10-16 | 0 | 0 | -- |
| Jun 17-23 | 0 | 15.2 | -- |
| Jun 24-30 | 1.2 | 2.8 | -- |
| Jul 1-7 | 9.3 | 0 | 54.0 |
| Jul 8-14 | 7.6 | 20.4 | 8.0 |
| Jul 15-21 | 14.8 | 24.5 | 30.0 |
| Jul 22-28 | 26.4 | 7.5 | -- |
| Jul 29-Aug | 40 | 13.2 | -- |
| Aug 5-11 | 10 | 0 | -- |
| Aug 12-18 | 55.3 | 0 | 12.0 |
| Aug 19-25 | 10.0 | 0 | -- |
| Aug 26-Sep 1 | 0 | 0 | 28.0 |
| Sep 2-8 | 2.9 | 9.6 | 34.0 |
| Sep 9-15 | 8.6 | 0 | -- |
| Sep 16-22 | 0 | 2.2 | -- |
| Sep 23-29 | 0 | 0 | -- |
| Sep 29-Oct 5 | 2.8 | 1.4 | 14.0 |

# CONCLUSION

*Peristenus* spp. appear to be widespread in lygus nymphs in the Pacific Northwest on a number of different lygus bug host plants and they may be bivoltine. *Peristenus* may be a key factor in reducing overall lygus bug populations and further work is necessary to describe its biology and potential for suppression of lygus populations.

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# Susceptibility of immature stages of the obliquebanded leafroller, *Choristoneura rosaceana* (Lepidoptera: Tortricidae) to fenoxycarb

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## ABSTRACT

In laboratory bioassays, eggs, larvae and pupae of the obliquebanded leafroller, *Choristoneura rosaceana* (Harris), were susceptible to the juvenile hormone analog, fenoxycarb. All eggs treated with 100 ppm failed to hatch; a dose dependent response was noticed at lower concentration ($LC_{50}$=1.59 ppm, $LC_{95}$=29.88 ppm). High larval and pupal mortality occurred when fully-grown larvae were exposed to fenoxycarb ($LC_{50}$=2.33 ppm, $LC_{95}$=32.67 ppm). Freshly formed pupae were slightly less susceptible ($LC_{50}$=30.50, $LC_{95}$=93.00) than eggs or larvae. Abnormal development (both in times required for growth and adult formation) was noted in all treatments.

**Key words:** *Choristoneura rosaceana*, obliquebanded leafroller, Tortricidae, insect growth regulator, fenoxycarb

## INTRODUCTION

The insect growth regulator, fenoxycarb (ethyl [2- (4-phenoxyphenoxy) ethyl] carbamate), is a broad spectrum juvenile hormone analog (JHA) which is effective against a number of insect pests including scale insects, fleas, mosquitoes, houseflies, cockroaches, ants, stored product insects, psyllids, and many species of Lepidoptera (Dorn *et al.* 1981; Masner *et al.* 1981; Charmillot 1989; Reid *et al.* 1990; Williams and Vail 1993; Gordon 1995). Dramatic effects occur when eggs are treated with fenoxycarb (Charmillot 1989); such treatments caused disruption of embryonic development and reduction of egg hatch. Hatching of eggs produced by treated adults was also reduced (Gordon 1995) and the last-instar larvae of lepidopteran insects were susceptible to this compound.

Tortricid leafrollers are among the major pests of tree fruits (Prokopy and Croft 1994). Fenoxycarb has been reported as effective against a number of tree fruit pests including codling moth, *Cydia pomonella* (L.), Oriental fruit moth, *Cydia molesta* (Busck), summer fruit tortrix, *Adoxophyes orana* (Fischer von Röslerstamm), fruit tree tortrix, *Archips podana* (Scopoli), and pear psylla, *Cacopsylla pyricoli* (Förster) (Schmid *et al.* 1978; de Reedè *et al.* 1984; Charmillot 1989; Krysan 1990; Higbee *et al.* 1995). The obliquebanded leafroller, *Choristoneura rosaceana* (Harris) is among the most important leafroller pests of many tree fruit and berry crops throughout North America (Chapman and Lienk 1971). It is widely distributed in the continental United States and Canada and is regarded as a particularly serious pest on red raspberry, apple, and hazelnut (Schuh and Mote 1948; Reissig 1978; AliNiazee 1986). Both foliar and fruit damage may occur, although fruit damage is by far the more troublesome.

Growers with obliquebanded leafroller problems rely on calendar applications of organophosphate insecticides to suppress the infestations. This causes severe disruption of

natural enemies. Fenoxycarb has only recently become available for use in the United States although it has been in use in Europe for nearly a decade. It appears to fit well in a "soft pesticide" program for tree fruit pests. Reported here is a laboratory study evaluating the effects of fenoxycarb on growth and development of eggs, larvae and pupae of the obliquebanded leafroller.

## MATERIALS AND METHODS

**Insects.** Insects needed for this study were obtained from a laboratory culture of the obliquebanded leafroller maintained at 24 ± 1° C on a 16L: 8D photoperiod for 2 years. The culture was initiated by collecting $5^{th}$-instar larvae and pupae from hazelnut trees near Corvallis, OR. Upon emergence, the adults were released in 3.75 cylindrical cartons, the inside surface of which was wrapped with wax paper for an oviposition surface. Adults were provided with a 5% sucrose solution for feeding. Eggs were obtained daily by cutting the wax paper and collecting the egg masses, which were placed in 500-mL plastic cups for hatching. Newly hatched larvae were collected and placed in 28 mL creamer cups containing an artificial diet (wheat-germ diet, Nutritional Biochem, Cleveland, OH) for larval development. The larvae were allowed to pupate in the media cups and pupae were collected at frequent intervals and placed in individual cups for emergence for use in bioassays.

**Egg bioassays.** Fenoxycarb was obtained from the Ciba-Geigy Co. (Greensboro, NC) as 25% wettable powder. Eggs (<12 h old) were dipped in six concentrations (0.1, 1, 5,10, 50, and 100 ppm) of fenoxycarb for 5 seconds and allowed to dry for 30 minutes. After drying, they were placed in 150mL clear plastic cups with hazelnut leaves and covered with lids. Two small holes covered with nylon mesh on the sides of the cups were provided for ventilation. A minimum of 50 eggs were maintained in each replication and treatments were replicated four times. Eclosion was monitored daily. All experiments were conducted in the Percival model growth chambers set at 24 ± 1° C and 70 ± 10% RH with 16L: 8D photoperiod.

**Larval bioassays.** Larval bioassays were conducted with early fifth instars, by selecting individuals of uniform size and treating them with different concentrations of fenoxycarb. Larvae were anesthetized with carbon dioxide after removal from the artificial diet cups. Immobilized larvae were then placed on filter paper and treated topically using a microapplicator syringe. One microliter of the different concentrations of fenoxycarb dissolved in acetone was applied to the dorsum of prothorax of each larva. Ten larvae were used in each replication and each treatment was replicated four times. After treatment the larvae were returned to their rearing cups with artificial diet, and post-treatment observations on larval mortality and morphological abnormalities were conducted daily at 24 ± 1° C and 16L: 8D photoperiod. Control larvae were treated with acetone. After pupation, pupae were removed from the diet cups, placed into empty cups and covered with plastic lids. The mortality of these pupae was assessed at frequent intervals and their successful development to the adult stage was recorded. Experiments were terminated after 30 days.

**Pupal bioassays.** The pupal bioassays were conducted with freshly-formed (<24 h old) pupae collected from laboratory cultures. The pupae were topically treated with different concentrations of fenoxycarb. One microliter of insecticide solution was applied to the dorsum of the prothorax of 10 individual pupae. After treatment, each pupa was placed separately in 150 mL clear plastic cups with lids; adult emergence and abnormalities were checked on a daily basis for a period of 30 days, at which time the experiments were

terminated. Control pupae were treated with acetone only. Each treatment was replicated three times.

**Statistical analysis.** The mortality data were plotted to determine LDP lines using Polo computer program, and $LC_{50}$ and $LC_{95}$ values were estimated through regression lines for each stage tested.

# RESULTS AND DISCUSSION

Freshly-oviposited eggs (<24 h old) of the obliquebanded leafroller were highly susceptible to fenoxycarb (Table 1). None of the eggs treated with 100 ppm hatched; effects were noticeable even at 10 ppm which caused about a 90 % reduction in egg hatch, demonstrating the ovicidal activity of this compound. Increasing rates of fenoxycarb resulted in a progressively decreasing egg hatch. Larvae hatched from the treated eggs exhibited no abnormal morphological effects.

**Table 1**

Regression analysis of fenoxycarb toxicity to different developmental stages of the obliquebanded leafroller showing concentration (ppm) for 50% ($LC_{50}$) and 95% ($LC_{95}$) mortality and slope of regression lines.

| Stages Tested | $LC_{50}$ (95% confidence limit) | $LC_{95}$ (95% confidence limit) | Slope (±SE) |
|---|---|---|---|
| Egg | 1.59 (0.65-2.91) | 29.88 (18.11-56.63) | 1.01 (0.07) |
| Larval | 2.33 (0.87-4.27) | 32.67 (17.13-100.31) | 1.12 (0.21) |
| Pupal | 30.50 (12.70-51.00) | 93.00 (56.30- 153.30) | 2.65 (0.57) |

Final-instar larvae were also susceptible to fenoxycarb in a dose-dependent fashion (Table 1). All treated larvae were killed at a rate of 100 ppm. At lower rates of 10 and 50 ppm substantial mortality was recorded. Most of the mortality at the higher doses tested occurred in the larval stage, whereas in the lower rate treatments, most of the treated larvae died in the pupal stage. In other words, at lower doses, a majority of the larvae were capable of molting to the pupal stage, but died soon after. Treated larvae showed prolongation of growth periods and some degree of malformation, including appearance of part pupal and part larval features, remnants of larval characteristics, and reduced adult emergence. These defects were more pronounced at lower doses.

When freshly-formed pupae (<24 h) were treated with fenoxycarb using the lowest dose of 1 ppm, more than 70% reduction in adult eclosion occurred. At higher rates of 100 and 200 ppm, more than 95% pupal mortality was recorded (Table 1). Those few adults that emerged at the higher dose treatments appeared normal, but their survival, longevity and fecundity, were not studied.

Fenoxycarb, in general, has an effect on insects similar to that of the natural juvenile hormone (JH), in that it disrupts metamorphosis. As in many other lepidopterans (Dorn *et al.* 1981; Charmillot 1989; Mulye and Gordon 1989), both eggs and mature larvae of the obliquebanded leafroller were susceptible to topical applications of fenoxycarb. In a related species, *Choristoneura fumiferana*, both adult and egg stages were highly susceptible to this JHA. Approximately 90% of the eggs deposited by treated adults failed to hatch (Gordon 1995). Our data suggest that all three stages tested, eggs, last instar larvae and young pupae were sensitive. Based on the $LC_{50}$ and $LC_{95}$ values (Table 1), the order of susceptibility was eggs > larvae > pupae.

The obliquebanded leafroller is a polyphagous pest of many tree fruit and berry crops in North America. It is generally controlled by the use of broad-spectrum organophosphate compounds. Although insecticide resistance has not been widely noted, development of resistance is nevertheless a serious threat as observed in other leafroller species (Meagher and Hull 1986; Cossentine and Jensen 1991). The results of the present laboratory study establish the toxicity of fenoxycarb to this insect. Further studies should determine the suitability of this compound as a selective control agent in suppressing obliquebanded leafroller populations in the field.

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# New species of *Hebecephalus* from British Columbia, Idaho and adjacent states (Rhynchota: Homoptera: Cicadellidae)*

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## ABSTRACT

Eight new nearctic leafhoppers of the genus *Hebecephalus* DeLong are described: *H. planaria* from British Columbia; *H. abies* from Utah; *H. chandleri* from Wyoming; and *H. crenulatus, H. ferrumequinum, H. picea, H. pugnus,* and *H. veretillum* from Idaho. All 27 known nearctic species are illustrated and their critical morphological characters are presented in key and tabular form, along with their geographic distribution. Evidence for endemism within southern British Columbia and the Pacific Northwest is noted.

## INTRODUCTION

Leafhoppers, the family Cicadellidae, include many species adapted to grasslands. They include a large number of species characteristic of prairies (Ross 1970) and are important organisms in characterizing and monitoring prairie sites (Hamilton 1995). They are likewise an important part of intermontane grassland environments, primarily in Colorado and the southwestern U.S. (Oman 1949). Sampling more northerly areas in recent years has disclosed a rich endemic fauna in the "Pacific Northwest" including southern British Columbia. This paper describes additional endemic species in the genus *Hebecephalus* DeLong.

Leafhoppers of the genus *Hebecephalus* are small, grass-feeding insects, their heads marked with broken dark crossbands, and wing venation outlined in dark brown or black, or with cells checkered or banded in black and white (Figs. 1-4). Females are readily distinguished from those of other genera by the prominent, black-margined median notch or slit on the pregenital sternite (Figs. 5-10). There are two species from Asia (Anufriev and Emeljanov 1988), one Nearctic transboreal species (*H. algidus* DeLong & Davidson) and three more on North American prairies (*H. occidentalis* Beamer & Tuthill, *H. rostratus* Beamer & Tuthill, *H. truncatus* Beamer & Tuthill) but the majority are confined to Cordilleran North America. The montane species occur in grassy valleys of Alaska (AK) and British Columbia (BC) south to the mountains of California (CA), Nevada (NV) and Arizona (AZ)[†]. The peculiar distribution patterns of these species is analysed here, following the description of new species.

## MATERIALS AND METHODS

Species are defined here, as elsewhere in my publications, following the guidelines of Ross (1974). These species definitions, wherever possible, are based on analyses of series: numerous specimens taken at the same time, preferably on a single plant species. Many are based on

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*Mailed January 1999

[†]The Neotropical *Deltocephalus* (*Hebecephalus*) *insularis* Van Duzee (1933) probably does not belong in this genus; Linnavuori (1959) places it tentatively in *Amplicephalus* DeLong.

material collected by A.R. Brooks, H.H. Ross and the author, now housed in the Canadian National Collection of Insects (CNCI) in Ottawa and other series collected over the past 20 years by R.F. Whitcomb, USDA-ARS, Beltsville, MD. These collections cover much of the native grasslands of North America, with the exception of those in low elevations of California and regions south of northern Mexico where *Hebecephalus* are rare or unknown. In all, more than 4,500 identifiable specimens of *Hebecephalus* were examined in this study.

This does not pretend to be a complete account of all the species that may occur in North America. Much additional collecting and analysis of material deposited in collections across the continent will be needed before a revision is possible.

Biological data and exact collecting localities are an important aspect of such studies. Label data is supplemented by information taken from collecting notes; this additional information is recorded in square brackets in the text.

Characters of the male genitalia must be examined by maceration in KOH followed by examination of whole structures suspended in glycerin. It is important that these structures not be mounted on microscope slides, as flattening such three-dimensional objects results in distortions that prevent accurate comparisons. For detailed descriptions of technique and body parts of leafhoppers, see Beirne (1956).

All figures of a given structure are drawn to a constant scale, except for the habitus illustrations (Figs. 1-4) which are diagrammatic.
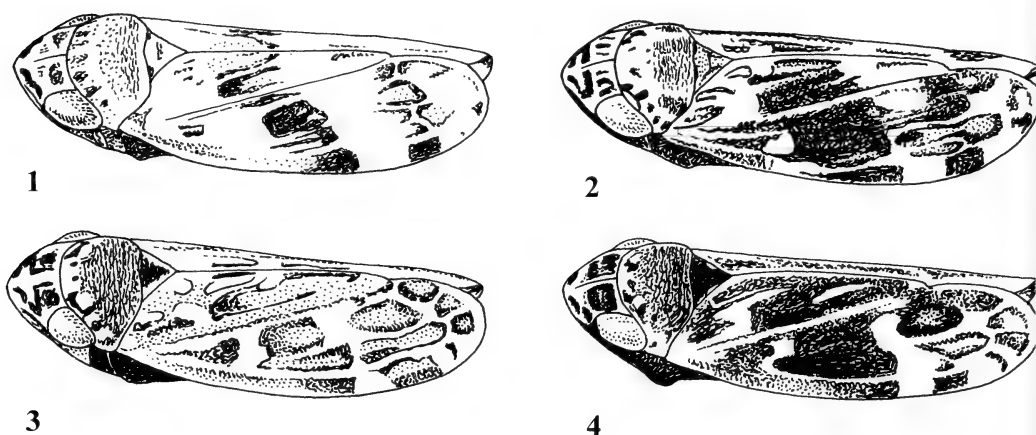


**Figures 1-4.** Colour variability of *Hebecephalus algidus* DeLong & Davidson from Eagle Plains, Yukon Territory, Canada. 1-2, obliquely banded forms; 3-4, checkered and pale-veined forms.

## SYSTEMATICS

The genus has been revised once (Beamer and Tuthill 1935) but various species have been added subsequently (DeLong and Davidson 1935; Beamer 1936; Wittlake and Beamer 1952; Beirne 1954; Hamilton and Ross 1972). Oman (1949) redefined the genus and split off various segregates as additional genera. Their removal left 19 described species, three of which were based on abnormal specimens (Wittlake and Beamer 1952) or variants (Beirne 1954) of previously described species:

(1) *Hebecephalus mornus* Beirne is a variant of *H. occidentalis* (Hamilton and Ross 1972).

(2) *H. creinus* Beirne appears to fall within the character variation of *H. borealis* DeLong & Davidson, and in fact the types of both species were taken from the same locality and year

(Nordegg, Alta., 1921). Specimens from the type-series of *borealis* have not been examined, so no formal synonymy is offered at present.

(3) *Hebecephalus pedecurtus* Wittlake & Beamer is based on 4 unidentifiable females and a pair of abnormal males. The latter show the incomplete ventral connective, shortened and simplified styles and feminized pygofers characteristic of nematode-parasitized individuals. From the form of the aedeagi, the males are most likely specimens of *H. rostratus*.

Three more species have been described subsequently (Hamilton and Ross 1972). This paper describes an additional eight species, bringing the total to 27 nearctic species.

Females of *Hebecephalus* show unique genitalic characters in only two species (Figs. 5, 10). At present, all other females cannot be identified with any degree of certainty in the absence of associated males. Colour patterns, apparently distinctive in some species, are rendered useless by their variability in other species (Figs. 1-4); body size and proportions overlap in many species. Accordingly, the most reliable specific characters are found in male genitalia.
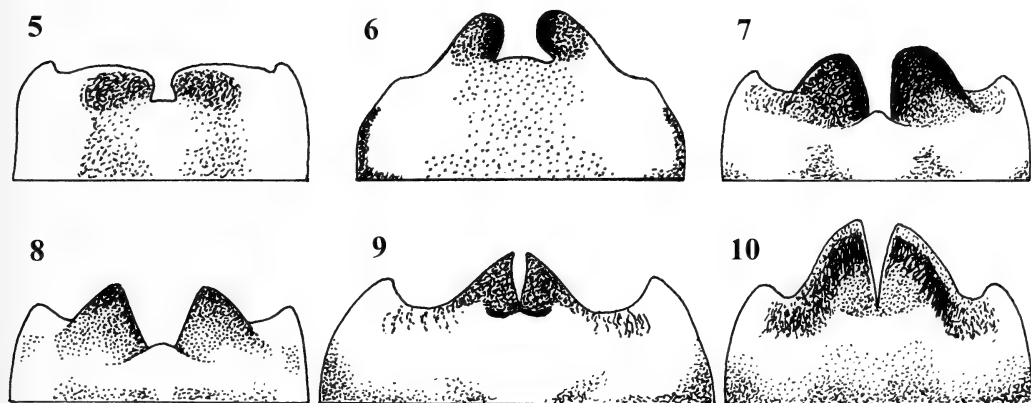


**Figures 5-10.** Pregenital sternites of *Hebecephalus* females. 5, *H. discessus* Beamer & Tuthill; 6, *H. pugnus* sp.nov.; 7, *H. ferrumequinum* sp.nov.; 8, *H. picea* sp.nov; 9, *H. chandleri* sp.nov.; 10, *H. algidus*.

Males of this genus resemble other grass-feeding Deltocephalini (=Deltocephalina *sensu* Hamilton 1975) in having a loop-shaped "ventral connective" which articulate the claspers ("styles") to the lower edge of the aedeagal base ("atrium"). They may be distinguished from other Deltocephalini by the form of the dorsal connective which articulates the base of the tenth tergite (or "anal tube") to the dorsal arm of the aedeagal base (Figs. 11-19 A). The dorsal connective in other related genera is a pair of ill-defined sclerous strips but in *Hebecephalus* it forms a transverse bar or plate, often with processes at either end (Figs. 11-19 B).

Characters useful at the species level (Table 1) include the outline of the male subgenital plates, armature of the pygofers (Figs. 20-29), shape of the aedeagus and dorsal connective (Figs. 11-19, 30-56) and armature of the style tip (Figs. 57-75). The style tip must be viewed with care as it is more or less twisted from the plane of its base, and appears to vary greatly in shape depending on the angle of study (Figs. 57-61).
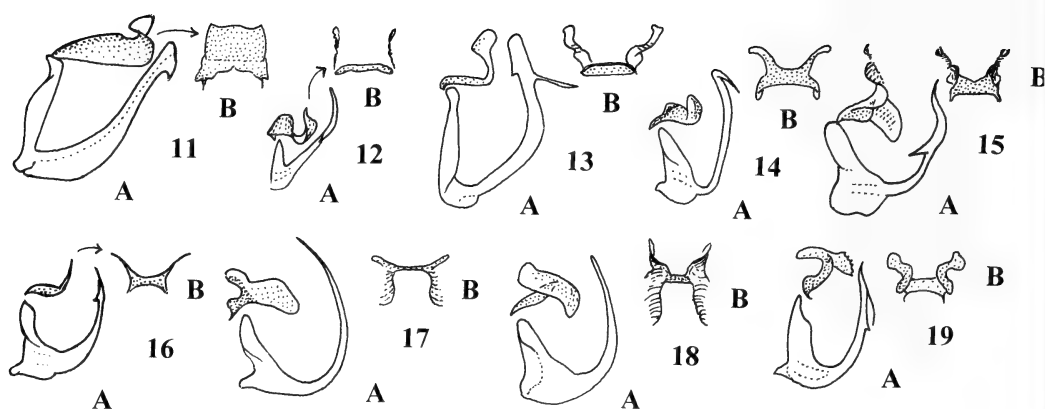
**Figures 11-19**. Aedeagi and dorsal connectives of *Hebecephalus*, lateral aspect (A) and caudoventral aspect of dorsal connective (B). 11, *H. vinculatus* (Ball); 12, *H. veretillum* sp.nov.; 13, *H. chandleri*; 14, *H. pugnus*; 15, *H. borealis* DeLong & Davidson; 16, *H. abies* sp.nov.; 17, *H. ferrumequinum*; 18, *H. crenulatus* sp.nov.; 19, *H. truncatus* Beamer & Tuthill.
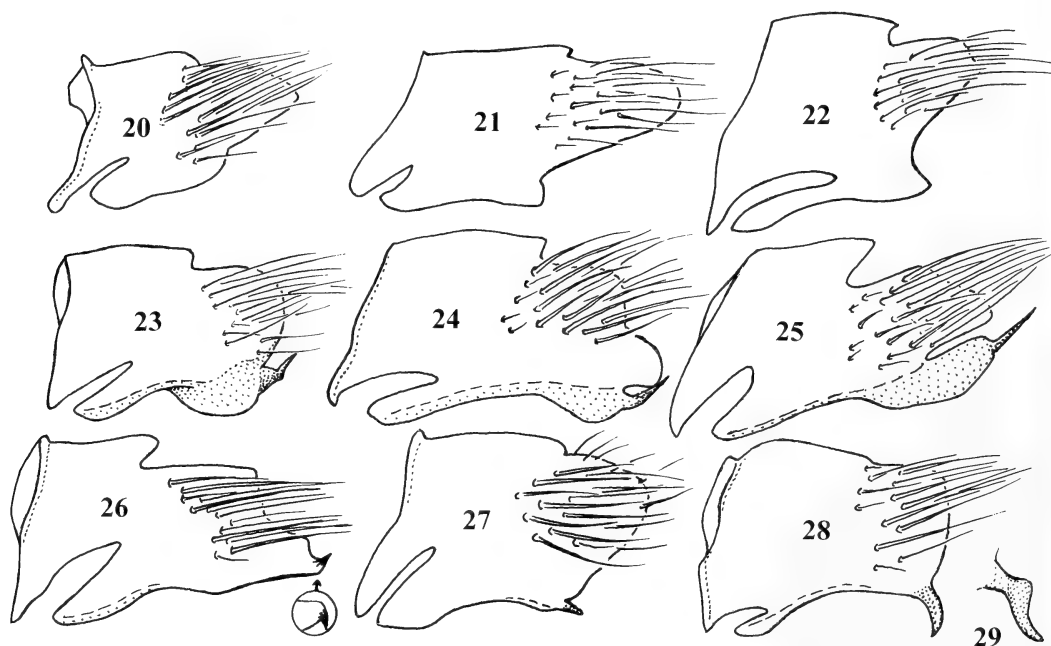


**Figures 20-29.** Male pygofers of *Hebecephalus*, lateral aspect. 20, *H. veretillum*; 21, *H. algidus*; 22, *H. chandleri*; 23, *H. pugnus*; 24, *H. adversus* Beamer & Tuthill; 25, *H. caecus* Beamer; 26, *H. borealis* (detail: pygofer tip, dorsal aspect); 27, *H. planaria* sp.nov.; 28, *H. crenulatus*; 29, pygofer process of *H. signatifrons* (Van Duzee).

**Table 1**

Character states of Nearctic species of *Hebecephalus*, as illustrated. **A**- female pregenital sternite (Figs. 5-10); **B**- aedeagus and dorsal connective, lateral aspect (Figs. 11-19 A and \*= fig. 3 in Hamilton and Ross 1972); **C**- dorsal connective, caudoventral aspect (Figs. 11-19 B); **D**- male pygofers (Figs. 20-29 and \*= fig. 1 in Hamilton and Ross 1972); **E**- aedeagus, caudoventral aspect (Figs. 30-56); **F**- style tip (Figs. 61-75); **G**- subgenital plates, as follows: figs. 1-2, 4 from Pl. LV (Beamer and Tuthill 1935), fig. 3 from Pl. LXVIII (Beamer 1936), fig. 5 from Pl. LVI (Beamer and Tuthill 1935), fig. 7 from Pl. 7 (DeLong and Davidson 1935) and #6 [not figured] represents elongate, divergent plates. Apomorphies boldfaced.

| trivial name | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| *veretillum* sp.nov. | ? | 12 | 12 | 20 | 33 | 68 | 6 |
| *discessus* Beamer & Tuthill | 5 | 11 | 14 | 20 | 54 | 62 | 1 |
| *planaria* sp.nov. | 6 | 11 | 14 | 27 | 47 | 73 | 1 |
| *irritus* Beamer | 6 | 14 | ? | 24 | 36 | 65 | 1 |
| *pugnus* sp.nov. | 6 | 14 | 14 | 23 | 49 | 66 | 2 |
| *filamentus* Hamilton & Ross | 6 | * | 14 | **28** | 35 | 74 | 1 |
| *callidus* (Ball) | 6 | 12 | 14 | **28** | **30** | 74 | 1 |
| *circus* Hamilton & Ross | ? | 12 | 16 | * | **31** | 72 | 1 |
| *crenulatus* sp.nov. | 6? | 18 | 18 | **28** | 44 | 67 | 1 |
| *sagittatus* Beamer & Tuthill | 6 | 16 | 18 | **28** | 41 | 73 | 1 |
| *occidentalis* Beamer & Tuthill | 6 | 19 | 16 | **28** | **55** | 73 | 1 |
| *rostratus* Beamer & Tuthill | 6 | 19 | 16 | **28** | **56** | 73 | 1 |
| *signatifrons* (Van Duzee) | 6 | 19 | 14 | **29** | 37 | **75** | 1 |
| *truncatus* Beamer & Tuthill | 6 | 19 | 19 | **28** | 48 | **75** | 4 |
| *crassus* DeLong | 6 | 12 | 17 | **28** | 46 | **75** | 2 |
| *abies* sp.nov. | 7 | 16 | 16 | **28** | 42 | **75** | 1 |
| *ferrumequinum* sp.nov. | 7 | 17 | 17 | **28** | 34 | **75** | 2 |
| *borealis* DeLong & Davidson | 7 | **15** | 15 | 26 | 32 | 61 | 7 |
| *picea* sp.nov. | **8** | **15** | 17 | **28** | 43 | 70 | 1 |
| *hilaris* Beamer | **8** | 16 | 16 | **28** | 45 | **69** | 2 |
| *beameri* Hamilton & Ross | **8** | 14 | ? | **28** | 50 | **71** | 1 |
| *adversus* Beamer & Tuthill | **8** | 16 | 14 | 24 | 39 | 65 | 5 |
| *caecus* Beamer | ? | 16 | 14 | 25 | 38 | 65 | 3 |
| *chandleri* sp.nov. | **9** | 13 | 13 | **22** | 36 | **64** | 3 |
| *vinculatus* (Ball) | **9** | 11 | 11 | **21** | 53 | **63** | 3 |
| *firmus* Beamer | **9** | 11 | 12 | **21** | **52** | **64** | 3 |
| *algidus* DeLong & Davidson | **10** | 11 | 12 | **21** | **51** | **64** | 3 |

No phylogeny of the genus can be attempted at present. Genitalic characters, which are all that were discovered to be useful for such an analysis (see derived characters, or apomorphies, in Table 1), show far too much convergence and parallelism (homoplasy) or unique developments (autapomorphy) to be reliable indicators of relationships. For example, the most distinctive aedeagal character (concave posterior face of shaft, Figs. 51-54) correlates well with other genitalic characters in three species related to *H. algidus* (Table 1) but appears to be convergent in the case of *H. discessus* Beamer & Tuthill which in all other characters stands far apart from the *algidus* group. Conversely, *H. chandleri* shares with the *algidus* group its highly characteristic style and female pregenital sternite, but has an aedeagal shape utterly unlike that of any other member of this species group.
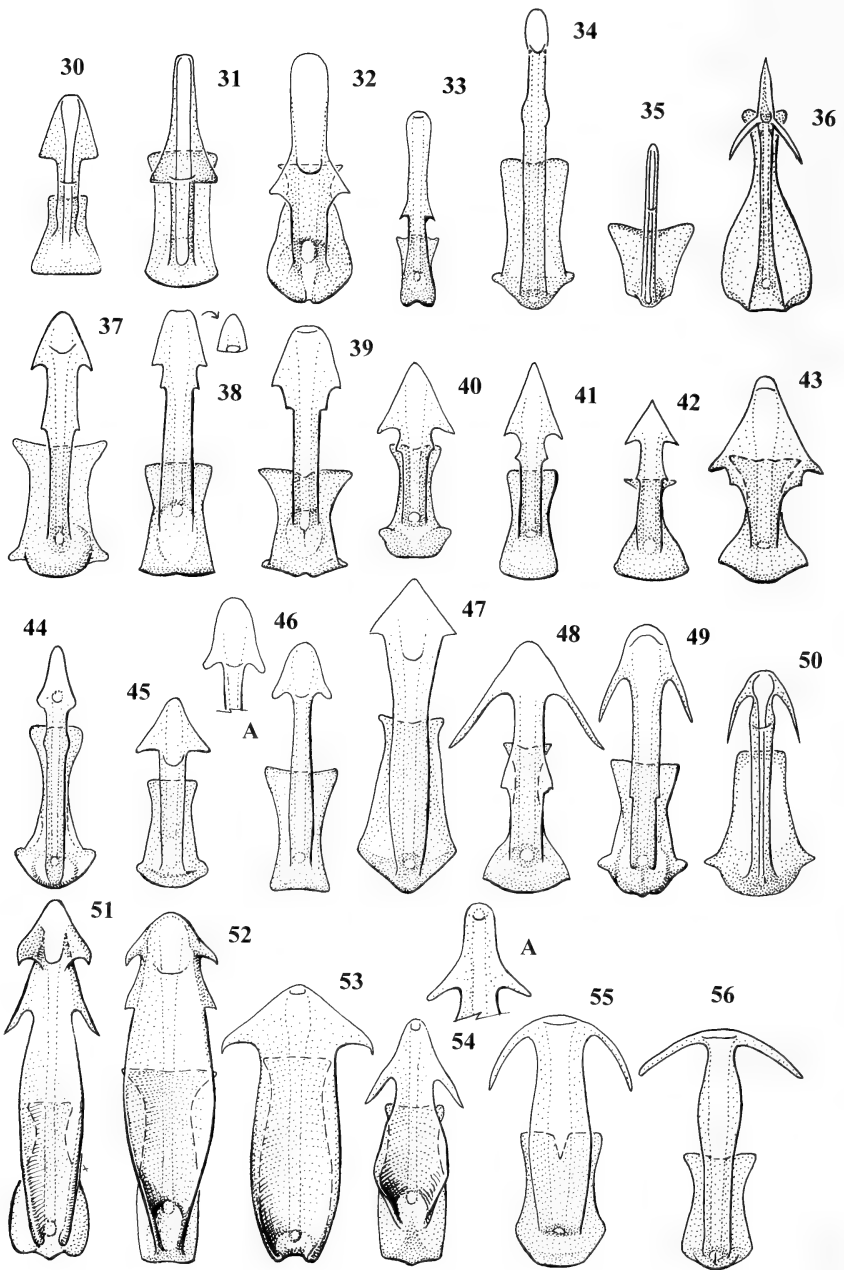
**Figures 30-56.** Aedeagi of *Hebecephalus*, caudoventral (longest) aspect. 30, *H. callidus* (Ball); 31, *H. circus* Hamilton & Ross; 32, *H. borealis*; 33, *H. veretillum*; 34, *H. ferrumequinum*; 35, *H. filamentus* Hamilton & Ross; 36, *H. chandleri*; 37, *H. signatifrons* (Van Duzee); 38, *H. caecus* (detail of tip from gonopore aspect); 39, *H. adversus*; 40-41, *H. sagittatus* Beamer & Tuthill; 42, *H. abies*; 43, *H. picea*; 44, *H. crenulatus*; 45, *H. hilaris* Beamer; 46, *H. crassus* DeLong and var. (A); 47, *H. planaria*; 48, *H. truncatus*; 49, *H. pugnus*; 50, *H. beameri* Hamilton & Ross; 51, *H. algidus*; 52, *H. firmus* Beamer; 53, *H. vinculatus*; 54, *H. discessus* and var. (A); 55, *H. occidentalis* Beamer & Tuthill; 56, *H. rostratus* Beamer & Tuthill.
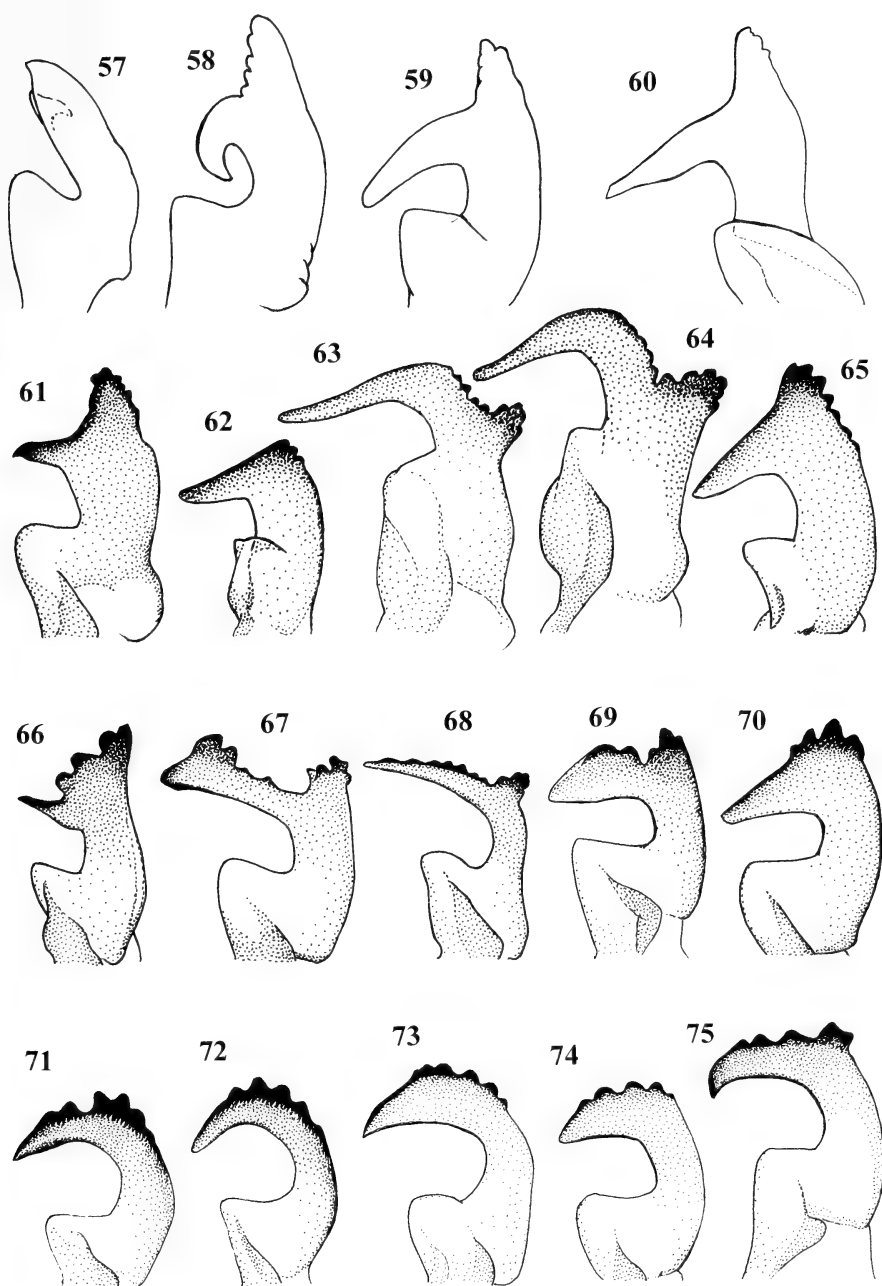
**Figures 57-75.** Right style tips of *Hebecephalus*, various angles. 57-61, *H. borealis* (57-60 in laterad rotation; 61 in anteriad rotation); 62, widest aspect of tip of *H. discessus*; 63, same, of *H. vinculatus*; 64, same, of *H. firmus*; 65, same, of *H. caecus*; 66, same, of *H. pugnus*; 67, same, of *H. crenulatus*; 68, same, of *H. veretillum*; 69, same, of *H. hilaris*; 70, same, of *H. picea*; 71, same, of *H. beameri*; 72, same, of *H. circus*; 73, same, of *H. planaria*; 74, same, of *H. truncatus*; 75, same, of *H. crassus*.

## Key to males of nearctic *Hebecephalus*

1.  Pygofer with process absent (Fig. 20), or lobate, ventral, located approximately
    halfway between tip of apical lobe and anteroventral angle (Figs. 21-22)........22
-   Pygofer with process sharp-tipped, apical or ventroapical, located distinctly closer to
    tip of apical lobe than to anteroventral angle (Figs. 23-29)..........................2
2.  Pygofer with process directed caudodorsad or laterad (Figs. 23-26)................17
-   Pygofer with process directed caudad or ventrad (Figs. 27-29).......................3
3.  Apical processes of aedeagus long and narrow (Figs. 48-50)........................14
-   Apical processes of aedeagus short and thick or absent (Figs. 37-47)..............4
4.  Tip of style with distinct notch between irregular marginal teeth (Figs. 67, 69)....13
-   Tip of style with low, evenly spaced marginal teeth (Figs. 72-75).....................5
5.  Aedeagus slender, without enlarged tip (Figs. 34-35)................................12
-   Tip of aedeagus spatulate to sagittate (Figs. 37-47)...................................6
6.  Enlarged tip of aedeagus as long as rest of shaft (Figs. 30, 43).....................11
-   Enlarged tip of aedeagus much shorter than rest of shaft (Figs. 37-42)..............7
7.  Aedeagal shaft short, only about as long as its base (Figs. 40-42)..................10
-   Aedeagal shaft long, nearly twice as long as its base (Figs. 37, 46-47).............8
8.  Aedeagal shaft robust, tip pointed (Fig. 47)..............................*planaria* sp.nov.
-   Aedeagal shaft slender, tip rounded (Figs. 37, 46)....................................9
9.  Pygofer spine slender, evenly curved (as in Fig. 28)................*crassus* DeLong
-   Pygofer spine wide at angled bend before base (Fig. 29)..*signatifrons* (Van Duzee)
10. Dorsal connective slender, without prominent processes (Fig. 16 B); style with
    coarse teeth half as deep as style tip between them (as in Fig. 75)..*abies* sp.nov.
-   Dorsal connective with broad, elongate lateral processes (as in Fig. 17 B); style with
    fine teeth a third as deep as style tip between them (as in Fig. 74)
    ..................................................................*sagittatus* Beamer & Tuthill
11. Aedeagal tip armed with 1 pair of teeth (Fig. 30).....................*callidus* (Ball)
-   Aedeagal tip armed with 2 pairs of teeth (Fig. 43)....................*picea* sp.nov.
12. Aedeagal shaft narrow compared to aedeagal base (Fig. 35); style with fine teeth a
    third as deep as style tip between them (as in Fig. 74)
    .................................................................*filamentus* Hamilton & Ross
-   Aedeagal shaft broad compared to aedeagal base (Fig. 34); style with coarse teeth
    half as deep as style tip between them (as in Fig. 75)......*ferrumequinum* sp.nov
13. Stylar notch much wider than deep (Fig. 67).......................*crenulatus* sp.nov.
-   Stylar notch narrow, as wide as deep (Fig. 69)........................*hilaris* Beamer
14. Subgenital plates with outer angles produced, tips thus appearing truncate in
    ventrolateral aspect; aedeagal processes straight (Fig. 48)
    ..................................................................*truncatus* Beamer & Tuthill
-   Subgenital plates rounded apically; aedeagal processes curved (Figs. 55-56)......15
15. Aedeagal processes directed laterad (Fig. 56)...........*rostratus* Beamer & Tuthill
-   Aedeagal processes directed ventrad (Figs. 50, 55)...................................16
16. Aedeagal shaft slender (Fig. 50); style tip with irregularly spaced teeth (Fig. 71)
    ..................................................................*beameri* Hamilton & Ross
-   Aedeagal shaft broad (Fig. 55); style tip with evenly spaced teeth (as in Fig. 73)
    ..................................................................*occidentalis* Beamer & Tuthill
17. Pygofer process directed laterad (Fig. 26); aedeagus in lateral aspect sinuate (Fig. 15
    A)..............................................................*borealis* DeLong & Davidson
-   Pygofer process directed caudad or caudodorsad (Figs. 27-29); aedeagus in lateral
    aspect curved evenly dorsad (Figs. 16-19 A)..........................................18
18. Lateral process of style short and narrow (Fig. 66)....................*pugnus* sp.nov.

| - | Lateral process of style long and thick (Fig. 65)..........................................19 |
| 19. | Aedeagus with tip bearing slender processes (as in Fig. 36)...........*irritus* Beamer |
| - | Aedeagus with unarmed tip (Fig. 31) or with short marginal teeth (Figs. 38-39)....20 |
| 20. | Aedeagus with elongate, tapered tip beyond marginal teeth (Fig. 31) |
| | ................................................................*circus* Hamilton & Ross |
| - | Aedeagus with short, spatulate tip beyond marginal teeth (Figs. 38-39)..............21 |
| 21. | Pygofer process set on small base (Fig. 24)................*adversus* Beamer & Tuthill |
| - | Pygofer process set on massive base (Fig. 25)..........................*caecus* Beamer |
| 22. | Aedeagal processes much longer than greatest width of shaft (Fig. 36) |
| | ..................................................................*chandleri* sp.nov. |
| - | Aedeagal processes shorter than greatest width of shaft (Figs. 33, 51-54)............23 |
| 23. | Aedeagal shaft slender, caudal surface flat (Fig. 33)....................*veretillum* sp.nov |
| - | Aedeagal shaft broad, caudal surface concave (Figs. 51-54)..........................24 |
| 24. | Aedeagal shaft with 2 pairs of processes (Figs. 51-52)..............................26 |
| - | Aedeagal shaft with 1 pair of processes (Figs. 53-54)...............................25 |
| 25. | Tip of aedeagal shaft broad, obtuse (Figs. 53) ...................*vinculatus* (Ball) |
| - | Tip of aedeagal shaft narrowed, sagittate (Figs. 54, 54A) |
| | ................................................................*discessus* Beamer & Tuthill |
| 26. | Aedeagal shaft slender, with lateral processes longer than preapical ones (Fig. 51); |
| | Alaska and northern Canada........................*algidus* DeLong & Davidson |
| - | Aedeagal shaft broad, with lateral processes shorter than preapical ones (Fig. 52); |
| | Wyoming.......................................................*firmus* Beamer |

### *Hebecephalus abies* sp.nov.
(Figs. 16, 42)

**Etymology.** Noun in apposition: *abies,* fir tree genus, in reference to the shape of the aedeagus.
**Diagnosis.** This species is distinguished from its congeners by a combination of genital characters. The female is nearly identical to that of *H. ferrumequinum* sp.nov. (only less angulate in the crown) and structurally similar to that of *H. borealis*, but distinctly smaller (the latter is 3.6-4.0 mm long). The male has a coarsely toothed, nearly straight stylar process like those of *H. crassus* (Fig. 75), *H. ferrumequinum, H. signatifrons* (Van Duzee), and *H. truncatus*. As in *H. signatifrons* and *H. truncatus*, the aedeagal shaft is armed with a pair of teeth near the midlength, but the shaft is scarcely longer than the aedeagal base. It is further distinguished from *H. signatifrons* in having an evenly curved pygofer process (c.f. Figs. 28, 29) and from *H. truncatus* in having rounded subgenital plate apices. The aedeagus of *H. abies* resembles that of *H. sagittatus* but the lateral teeth on the shaft are much farther from the sagittate apex.
**Description.** Head parabolically produced, crown 0.9x as long as width between eyes. Crown marked with 6 dark spots usual for genus (as in Beirne 1956, figs. 489-494); upper half of face and tip of clypellus black spotted with ivory, lower half ivory with black spots; pronotum with irregular dark brown markings on anterior third separated from paler mottling on posterior third by arcuate paler band; tegmina with veins outlined in dark brown.

Male: length of crown 0.33 mm; width across eyes 0.85 mm; length 2.8-3.0 mm. Pygofer quadrate, concave ventrally, setose, armed with ventroapical process curved ventrad or caudoventrad (as in Fig. 28); subgenital plates short, appressed, tips obtuse, rounded; aedeagal shaft in lateral aspect curved dorsad (Fig. 16 A), in caudoventral aspect shaft short, parallel-margined, half as wide as aedeagal base, as wide as dorsal atrial arm, shaft armed with paired teeth near midlength, tip acute (Fig. 42); style tip nearly straight, coarsely toothed (as in Fig. 75); dorsal connective an X-shaped bar with elongate, slender arms extending to base of anal tube and shorter ones extending to atrial arm (Fig. 16 B).

Female: length of crown 0.4 mm; width across eyes 0.9 mm; length 2.9-3.1 mm. Pregenital sternite with large, black rounded lobes separated by narrow notch extending at least half way to base (as in Fig. 7).

**Types.** Holotype male, **USA.** *UT-* Tabiona, 11 June 1992 (K.G.A. Hamilton) [in dry tributary of Duchesne River ca. 4 km SE of town; on mixture of *Poa, Distichlis stricta* and other grasses]. Paratypes from **USA.** *UT-* 2 nymphs, 1 male, 4 females, same data as holotype; 2 nymphs, 2 males, 2 females, same data except 41 km SW Duchesne; 3 nymphs, 2 males, 1 female, same data, [2 km N] Mountain Home; 1 male, 1 female, Ouray, 4 Aug. 1986 (R.F. Whitcomb) 002506. All types No. 22377 in CNCI.

**Remarks.** All sites come from Duchesne and Uintah counties in NE Utah, but occur at a wide variety of elevations, from valley bottom in the Green River canyon at Ouray, 2000 m above sea level (ASL), to 2400m ASL in the Patmos mountains SW of Duchesne.

### *Hebecephalus chandleri* sp.nov.
### (Figs. 9, 13, 22, 36)

**Etymology.** Patronym, named for D.S. Chandler, who collected the type series.

**Diagnosis.** Males are distinguished from their Nearctic congeners by the narrow aedeagus with long processes; females resemble those of *H. vinculatus* (Ball) and *H. firmus* Beamer. The aedeagus is almost identical to that of *H. atralbus* Emeljanov (c.f. Figs. 13, 36 and Anufriev and Emeljanov 1988, plate 182 Figs. 10-11) from Siberia. The latter differs from the Nearctic species in a much darker wing colour (c.f. Figs. 1, 2) which is consistent in over 60 specimens from four localities (Emeljanov 1976) and a style without produced inner angle, a feature consistently visible (regardless of viewing angle) in four Nearctic species including *chandleri* (Figs. 63-64). The same four species have female pregenital sternites with close-set, pointed lobes (Figs. 9-10), which is probably an apomorphic character showing the close relationship of these species.

**Description.** Head obtusely pointed, crown 0.75x as long as width between eyes. Crown marked with 2 transverse, broken bars followed by 2-4 longitudinal streaks (as in Fig. 2); upper half of face black spotted with ivory, lower half variable from nearly uniform ivory, to heavily lined with black on sutures and margins; pronotum with pale, irregular dark brown markings on anterior third; tegmina with discal and costal cells black (as in Fig. 1), lying on oblique pale brown bands extending across discal and apical cells.

Male: length of crown 0.35 mm; width across eyes 0.95 mm; length 3.1 mm. Pygofer broad, apex furcate, upper lobe setose, unarmed (Fig. 22); subgenital plates long, appressed, apices obtuse as in *H. algidus*; aedeagus slender, shaft in lateral aspect strongly curved near midlength, bearing long processes directed caudad and toothed on anterior face just before spatulate tip (Fig. 13 A), in caudoventral aspect shaft slender, scarcely wider than strongly tapered atrial arm of bulbous aedeagal base, shaft armed with divergent preapical processes, tip pointed (Fig. 36); style tip bearing long, sinuate, narrow process finely toothed at base, and prominent, coarsely toothed inner angle (as in Fig. 64); dorsal connective a transverse bar with broad, twisted arms extending to base of anal tube (Fig. 13 B).

Female: length of crown 0.4 mm; width across eyes 1.0 mm; length 3.2-3.4 mm. Pregenital sternite with sharp-tipped, black lobes separated by slit extending less than half way to base (Fig. 9).

**Type.** Holotype male, **USA.** *WY-* Sibley Lake Campground in Bighorn Mountains, Sheridan Co., 22 July 1988 (D.S. Chandler). Paratypes: 6 females, same data as holotype. All types No. 22378 in CNCI.

**Remarks.** Emeljanov (1976) implied, but did not state, that the pygofers of *H. atralbus* resemble those of *H. algidus*. If so, the short, furcate pygofers of *H. chandleri* are unique.

## *Hebecephalus crenulatus* sp.nov.
(Figs. 18, 28, 44, 67)

**Etymology.** Adjective: *crenulatus,* battlemented, in reference to the shape of the style.

**Diagnosis.** This species is based on a single male, but its wide, nearly toothless area on the style tip between prominent teeth is so distinctive that it cannot represent a mere variant of another species. Its exact affinities cannot be ascertained based only on the male characters analysed here. The notched style tip suggests an affinity with *H. hilaris* Beamer.

**Description.** Head roundedly produced, crown 0.75x as long as width between eyes. Crown marked with six dark spots usual for genus, the posterior pair by far the largest, nearly circular; upper half of face black spotted with ivory, lower half ivory spotted with black; pronotum mottled with brown; tegmina with veins outlined in dark brown.

Male: length of crown 0.3 mm; width across eyes 0.85 mm; length 3.1 mm. Pygofer (Fig. 28) and subgenital plates as in *H. abies*; aedeagal shaft in lateral aspect curved dorsad (Fig. 18 A), in caudoventral aspect shaft slender, scarcely wider than aedeagal base, as wide as dorsal atrial arm near midlength, shaft weakly expanded twice beyond midlength, tip bluntly pointed (Fig. 44); style tip elongate, coarsely toothed either side of wide, nearly toothless area between prominent inner and outer angles (Fig. 67); dorsal connective a short, narrow, transverse bar with large, wrinkled processes extending nearly to aedeagal shaft (Fig. 18 B).

Female [based on non-type material]: length of crown 0.35 mm; width across eyes 0.9 mm; length 3.2-3.3 mm. Pregenital sternite with rounded black lobes separated by narrow notch extending less than half way to base (as in Fig. 6).

**Type.** Holotype male, **USA.** *ID-* Mud Lake, 19 June 1984 (K.G.A. Hamilton) [silty sand area 2 km W of town; on mixture of *Agropyron, Oryzopsis* and wild oats]; No. 22379 in CNCI.

**Remarks.** Females taken at other Snake River plain sites (Arco, Howe and Rexbury) all have heads 1.0 mm wide, and are therefore not referable to this species. A series of females from an adjacent valley (Tendoy, ID) have longer, more distinctly produced crowns. Two females taken near the Utah border (15 km W Stone, ID) on 16 June 1992 by the author have the head proportions and colour similar to those of the male type of *H. crenulatus* and are here tentatively associated with this species, though not considered as type material.

## *Hebecephalus ferrumequinum* sp.nov.
(Figs. 7, 17, 34)

**Etymology.** Noun in apposition: *ferru-,* of iron; *equus,* horse, in reference to the type locality, Railroad Canyon.

**Diagnosis.** This species is distinguished from its congeners by a combination of genital characters. The female is nearly identical to that of *H. abies* sp.nov. (only more angulate in the crown) and structurally similar to that of *H. borealis,* but distinctly smaller (see Diagnosis of *H. abies*). This species has an aedeagus nearly as strongly curved as that of *H. filamentus* Hamilton & Ross (Hamilton and Ross1972, Fig. 3) but the shaft is much longer and wider in proportion to the aedeagal base (c.f. Figs. 34, 35). From *H. filamentus* it also differs in the straighter, more strongly toothed style process (c.f. Figs. 73, 75).

**Description.** Head bluntly angled, crown 0.8x as long as width between eyes. Crown marked with six dark spots usual for genus (as in Beirne 1956, figs. 489-494); upper half of face and tip of clypellus black spotted with ivory; pronotum with irregular dark brown markings; tegmina with veins outlined in dark brown.

Male: length of crown 0.33 mm; width across eyes 0.9 mm; length 2.7-3.0 mm. Pygofer as in *H. crenulatus* (Fig. 28); subgenital plates appressed, tips produced, as in *H. crassus* (Beamer and Tuthill 1935, pl. LV Fig. 2); aedeagus slender, shaft in lateral aspect strongly curved anterodorsad (Fig. 17 A), in caudoventral aspect shaft about 2x wider than aedeagal base, shaft armed with tiny paired teeth just below gonopore and low, rounded prominences beyond

midlength, tip rounded (Fig. 34); style tip as in *H. crassus* (Fig. 75); dorsal connective a transverse bar with large, wrinkled processes (Fig. 17 B) extending half way to aedeagal shaft.

Female: length of crown 0.37 mm; width across eyes 0.95 mm; length 2.9-3.2 mm. Pregenital sternite with large, black rounded lobes separated by narrow notch extending at least half way to base (as in Fig. 7).

**Types.** Holotype male, **USA.** *ID*- Railroad Canyon 2200m ASL, 12 km NE Leadore, 4 June 1992 (K.G.A. Hamilton) [shallow slope alongside road; grasses mainly *Festuca idahoensis* Elmer]. Paratypes: 15 nymphs, 38 males, 19 females, same data as holotype. All types No. 22380 in CNCI.

**Remarks.** The type locality is the only known site for this species. It is 3 km W of the summit of Bannock Pass on the ID-MT border and lies 300 m lower than the pass.

### *Hebecephalus picea* sp.nov.
(Figs. 8, 43, 70)

**Etymology.** Noun in apposition: *picea,* spruce tree genus, in reference to the shape of the aedeagus.

**Diagnosis.** The few females examined fall within the range of variation of *H. hilaris, H. beameri* Hamilton & Ross and *H. adversus*. The male is distinguished by its short, very broad aedeagal shaft which otherwise resembles that of *H. sagittatus*. These two species also differ in the styles: the teeth on the inner angle are more strongly developed in *H. picea*.

**Description.** Head parabolically produced, crown 0.95x as long as width between eyes. Colour and markings as in *H. abies*, but pronotum without pale band.

Male: length of crown 0.35 mm; width across eyes 0.9 mm; length 2.8-2.9 mm. Pygofer as in *H. abies* (Fig. 28); subgenital plates short, tips rounded; aedeagus short, shaft in lateral aspect weakly sinuate, curved dorsad at tip (as in Fig. 15 A), in caudoventral aspect shaft broadly triangular, wider than aedeagal base and twice as wide as dorsal atrial arm at midlength, shaft armed with two pairs of small teeth near midlength, tip bluntly pointed (Fig. 43); style tip with stout process strongly tapered almost to a point, coarsely toothed on inner angle (Fig. 70); dorsal connective as in *H. ferrumequinum* (Fig. 17 B).

Female: length of crown 0.4 mm; width across eyes 1.0 mm; length 3.1-3.2 mm. Pregenital sternite with large, black pointed lobes separated by V-shaped notch extending at least half way to base (Fig. 8).

**Type.** Holotype male, **USA.** *ID*- 10 km NW Mackay, 19 June 1984 (K.G.A. Hamilton) [stony plain with scattered clumps of *Oryzopsis hymenoides* (Roem. & Schult.)]. Paratypes: 2 nymphs, 1 male, 2 females, same data as holotype. All types No. 22381 in CNCI.

**Remarks.** The type locality was revisited on 6 June 1992 but no additional specimens of *Hebecephalus* were found. Unassociated females taken elsewhere in southern Idaho have rounded pregenital lobes separated by a narrower notch and cannot be the same species although their identity cannot be established with certainty (see Remarks under *H. crenulatus*).

### *Hebecephalus planaria* sp.nov.
(Figs. 27, 47, 73)

**Etymology.** Noun in apposition: *planaria,* flatworm genus, in reference to the shape of the aedeagus.

**Diagnosis.** Females of this species cannot be distinguished from those of many other *Hebecephalus*. Males have a broad, flat aedeagal shaft that is unique in the genus. The relationship of this species to its congeners is obscure at present.

**Description.** Head bluntly pointed, crown 0.8x as long as width between eyes. Colour and markings as in *H. abies*, but pronotum without pale band, or this narrow and irregular.

Male: length of crown 0.38 mm; width across eyes 0.9 mm; length 3.3-3.6 mm. Pygofer parallel-margined as far as short ventral spur directed caudad, apex short and bluntly conical, setose (Fig. 27); subgenital plates short, tips rounded; aedeagus large, shaft in lateral aspect nearly straight, curved dorsad near base (as in Fig. 11 A), in caudoventral aspect shaft broad, half as wide as aedeagal base, scarcely narrower than apex of dorsal atrial arm, shaft armed with paired preapical teeth, tip pointed (Fig. 47); style tip strongly curved, finely toothed, inner angle absent (Fig. 73); dorsal connective as in *H. chandleri* (Fig. 13 B).

Female: length of crown 0.4 mm; width across eyes 1.0 mm; length 3.5-3.7 mm. Pregenital sternite with rounded, black lobes separated by narrow notch extending less than half way to base (as in Fig. 6).

**Types.** Holotype male, **Canada.** *BC*- 10 km NE Douglas Lake, 5 June 1987 (K.G.A. Hamilton) [shallow valley in rangeland; on *Poa pratensis* L.] Paratypes: 6 males, 11 females, same data as holotype. All types No. 22382 in CNCI.

**Remarks.** Although samples were taken at four other sites in the same extensive ranch area (over a distance of 22 km) no additional populations of this species were found. Unassociated females from other sites in southern BC are too small to be this species.

### *Hebecephalus pugnus* sp.nov.
(Figs. 6, 14, 23, 49, 66)

**Etymology.** Noun in apposition: *pugnus,* fist, in reference to the shape of the style.

**Diagnosis.** Females of this species cannot be distinguished from those of many other *Hebecephalus*. Males have an unique style, its tip resembling in outline a fist with thumb extended. The relationship of this species to its congeners is obscure at present.

**Description.** Head parabolically produced, crown 0.8x as long as width between eyes. Colour and markings as in *H. abies*, but pronotum without pale band.

Male: length of crown 0.35 mm; width across eyes 0.8 mm; length 3.0-3.4 mm. Pygofer weakly tapered, distinctly constricted at midlength, apex with rounded lobes above and below short spine directed caudodorsad, upper lobe setose (Fig. 23); subgenital plates as in *H. ferrumequinum*; aedeagus long, shaft in lateral aspect curved dorsad at base and weakly curved cephalad near tip, nearly straight between (Fig. 14 A), in caudoventral aspect shaft slender, scarcely wider than aedeagal base, shaft armed with low, paired teeth below midlength and spiniform processes a quarter length of shaft on rounded tip of shaft (Fig. 49); style tip short, coarsely toothed, those on inner angle most prominent, that on outer angle slender, resembling an extended thumb on a clenched fist (Fig. 66); dorsal connective a transverse plate with slender, curved arms extending to base of anal tube and shorter ones to atrial arm of aedeagus (Fig. 14 B).

Female: length of crown 0.38 mm; width across eyes 0.9 mm; length 3.0-3.4 mm. Pregenital sternite with rounded, black lobes separated by narrow notch extending less than half way to base (Fig. 6).

**Types.** Holotype male, **USA.** *ID*- 12 km S Hamer, 19 June 1984 (K.G.A. Hamilton). Paratypes: 3 males, 4 females, same data as holotype; 1 nymph, 2 males, 3 females, Willow Ck. Summit 2350m ASL, SE Challis, 19 June 1984 (K.G.A. Hamilton). All types No. 22383 in CNCI.

**Remarks.** An unassociated pair of females from the vicinity of the type locality (9 km W Rexburg, ID) was collected on 19 June 1984 by the author.

### *Hebecephalus veretillum* sp.nov.
(Figs. 12, 20, 33, 68)

**Etymology.** Noun in apposition: *veretillum,* little genitalia.

**Diagnosis.** This species is based on a single male. Its unarmed pygofer and small, slender aedeagus suggests that it is deformed, but its slender, serrate, blade-like style tip is distinctive and

unlike the lobate style tips of abnormal specimens. Its exact affinities cannot be ascertained based only on the male characters analysed here. Possibly it represents a basal lineage in the genus.

**Description.** Head parabolically produced, crown 0.95x as long as width between eyes. Crown marked with six dark spots usual for genus (as in Beirne 1956, figs. 489-494); face black spotted with ivory, largely pale on genae; pronotum with irregular dark brown markings on anterior third separated from paler mottling on posterior third by arcuate paler band; tegmina with veins outlined in dark brown, except on basal fifth, on costal cross veins and vein tips, and on oblique pale band extending across bases of anteapical cells.

Male: length of crown 0.32 mm; width across eyes 0.8 mm; length 2.5 mm. Pygofer conical, slightly constricted just beyond midlength, highly setose but otherwise unarmed (Fig. 20); subgenital plates elongate, apically divergent, tips obtuse; aedeagus small, shaft in lateral aspect nearly straight, curved dorsad at tip (Fig. 12 A), in caudoventral aspect shaft slender, scarcely wider than aedeagal base, shaft armed with paired teeth near midlength, tip rounded (Fig. 33); style tip narrow, finely toothed, those on inner angle most prominent (Fig. 68); dorsal connective a transverse bar with slender, twisted arms extending to base of anal tube (Fig. 12 B).

Female unknown.

**Type.** Holotype male, **USA.** *ID*- Ketcham, 18 June 1992 (K.G.A. Hamilton) [W-facing slope at N edge of town; on mixture of *Poa, Agropyron* and *Elymus*]; No. 22384 in CNCI.

**Remarks.** A revisit to the type locality on 28 May 1995 failed to find any additional specimens of *Hebecephalus*, possibly because the spring was unusually late that year and the grasses were still quite low.

## CONCLUSIONS

Localized populations of *Hebecephalus* are highly regionalized in areas that suffered moderate Pleistocene glaciation. Of the 27 Nearctic species known to date, all but six have been found in or adjacent to Idaho (ID: Table 2), and at least half of the species probably inhabit that one state. British Columbia has the next largest fauna of *Hebecephalus* (nine species), Wyoming has seven, while Utah and Montana have six each. Additional, as yet undiscovered, species are likely to be found in these five political areas plus the adjacent state of Washington, which has four such species. All other states and provinces have five or fewer species of *Hebecephalus* and additional species are not anticipated from these areas.

Endemism is also reflected in the small number of sites where regionalized species were found. Nine species are presently known from only a single site (marked by an asterisk in Table 2). Four of these sites are in Idaho, and four others are in adjacent political areas (BC, NV, WY). Repeated collecting there has yielded additional populations of such regionalized species in only four cases (or possibly five; see *H. crenulatus* sp.nov.)

Conversely, five other species of *Hebecephalus* are among the most widespread of grassland leafhoppers (boldfaced in Table 2), ranging from Utah north to the Yukon, or Alaska east to northern Québec, and from Arizona east to Illinois, with very large gaps between populations. These five widespread species include at least two pairs of closely related species and thus appear to represent cases of divergence in lifestyle. The remaining nine species are usually known from only two or three states or provinces, while *H. callidus* (Ball) is slightly more widespread, being found in southern British Columbia and its three adjacent states: ID, MT, WA. In short, a few of species in this genus are exceptionally good dispersers while the majority have unusually restricted distributions for grassland leafhoppers.

Many species in this genus are found only within certain valleys or passes in the Rocky Mountains where their host grasses are common. Such endemism cannot be attributable to the restricted range of a single host plant. Most species of *Hebecephalus* are generalist feeders on

## Table 2

Check list and distribution of Nearctic species of *Hebecephalus*.  Boldfaced: widely distributed species.  Asterisk (*): known from only one site.

*abies* sp.nov. - UT

*adversus* Beamer & Tuthill - MT, NV[1], OR [+*ID?*]

**algidus DeLong & Davidson - AK; AB, BC, MB, NF, NT[2], QC, YK**

*beameri* Hamilton & Ross - *AK

*borealis* DeLong & Davidson - AB, BC, SK

*caecus* Beamer - ID, OR

*callidus* (Ball) - ID, MT, WA; BC

*chandleri* sp.nov. - *WY

*circus* Hamilton & Ross - CO, UT

*crassus* DeLong - ID, WY; BC [*YK* = see *sagittatus*]

[*creinus* Beirne: see *borealis, algidus*]

*crenulatus* sp.nov. - *ID

*discessus* Beamer & Tuthill - CA

*ferrumequinum* sp.nov. - *ID

*filamentus* Hamilton & Ross - UT, WY

*firmus* Beamer - MT, WA, WY[3] [+ *ID?*]

*hilaris* Beamer - *WY

*irritus* Beamer - *NV

[*mornus* Beirne: see *occidentalis*]

**occidentalis Beamer & Tuthill - AK, AZ, CO, ID, MT, ND, OR, SD, UT, WA, WY; AB, BC, SK, MB, YK**

[*pedecurtus* Wittlake & Beamer: see *rostratus*]

*picea* sp.nov. - *ID

*planaria* sp.nov. - *BC

*pugnus* sp.nov. – ID

**rostratus Beamer & Tuthill - AZ, CO, ID, IL[4], KS, MT, NM, ND, OR, SD, UT, WA, WY; AB, BC, MB** [+*NE?*[5]; *YK* = see *truncatus*]

**sagittatus Beamer & Tuthill - ID, OR, UT; BC, YK** [*IL* = see *rostratus*]

*signatifrons* (Van Duzee) - AZ, CO

**truncatus Beamer & Tuthill - MT; AB, BC, MB, SK, YK[6]** *[+ID?]*

*veretillum* sp.nov. - *ID

*vinculatus* (Ball) - CO [*WY* = see *firmus*]

[1]Incorrectly recorded (Beamer and Tuthill 1935) from "Barclay, Utah"
[2]Incorrectly recorded (Beirne 1956) as *H. creinus.*
[3]Incorrectly recorded (Beamer and Tuthill 1935) as *H. vinculatus.*
[4]Incorrectly recorded (DeLong 1948) as *sagittatus.*
[5]Unverified record by DeLong (1926).
[6]Incorrectly recorded (Hamilton 1997) as H. *rostratus.*

*Festuca, Muhlenbergia, Oryzopsis, Poa, Puccinellia, Spartina* and *Stipa*. Only one species of *Hebecephalus* is recorded from a single grass host: *H. adversus* Beamer & Tuthill on giant wild rye, *Elymus cinereus* Scribn. & Merr. in Montana. Instead, the members of *Hebecephalus* are usually restricted to areas where mixtures of cool-season grasses are dominant (such leafhoppers are seldom monophagous). Such open grasslands must have been very limited in the Pacific Northwest during the cold and wet era of the Pleistocene, probably restricted to steep, sun-warmed, south-facing slopes in suitable valleys. This suggests that the high degree of endemism in *Hebecephalus* results from highly isolated glacial-age populations.

Unfortunately, detailed patterns of distribution are not yet discernible. Much additional collecting in the Pacific Northwest will be needed to confirm the hypotheses of regional endemism and geographic isolation.

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# Mortality of mountain pine beetle larvae, *Dendroctonus ponderosae* (Coleoptera: Scolytidae) in logs of lodgepole pine (*Pinus contorta* var. *latifolia*) at constant low temperatures

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## ABSTRACT

Mortality of mountain pine beetle larvae (*Dendroctonus ponderosae* Hopkins) in naturally infested logs of lodgepole pine (*Pinus contorta* var. *latifolia* Douglas) held at constant low temperatures was investigated. The logs were brought to the laboratory in mid-fall and stored at -6.6 °C for 10 weeks, then at -12.2 °C for 2 weeks prior to the start of the experiments to allow the larvae to acquire maximum cold hardiness. The logs were exposed to constant temperatures of -17.8, -23.3, -28.8, and -34.4 °C for 1, 2, 4, 8, 16, and 32 days. Mortality of larvae was recorded for two size classes: 1st- and 2nd-instar larvae and 3rd- and 4th-instar larvae. Mortality in logs stored at -12.2 °C served as control. Mortality was negatively correlated with log diameter, bark thickness, brood density, and gallery length per $m^2$, but only the correlation with log diameter was statistically significant. Mortality in both small and large larvae was inversely related to temperature and directly related to duration of treatment. Mortality of the small larvae was positively correlated to mortality of large larvae but mortality of the latter was significantly lower. Multiple regression was used to describe the relationship between temperature, duration of treatment, and log diameter for both larval groups. Results are discussed in relation to published information.

**Key words**: *Dendroctonus monticolae*, Scolytidae, *Pinus contorta*, mortality, low temperature, cold hardiness

## INTRODUCTION

Over winter mortality from low temperatures is one of the main factors which regulates mountain pine beetle (mpb) populations (Safranyik 1978). To improve survival, a number of arthropods rely on supercooling to avoid freezing (Gehrken 1989). Mountain pine beetle larvae acquire and increase cold-hardiness through gradual accumulation of glycerol in their blood in response to gradually decreasing temperature, and lose it in the opposite manner (Somme 1964); thus, cold-hardiness is usually greatest in the period from December to February (Wygant 1940). Unseasonably low temperatures early in the fall, or late in the spring, reduce survival rates in all developmental stages. Because mountain pine beetles generally overwinter as larvae in their host trees in British Columbia, the effects of low temperatures on larval survival are of particular interest.

The lethal low temperature threshold for exposed larvae in laboratory experiments ranges between -34 °C and -37 °C (Wygant 1940; Somme 1964), with more mature larvae having the lowest threshold (Amman 1973). Sub-cortical temperatures are modified by such host characteristics as bark thickness, tree diameter, and wood moisture content (Wygant 1940) and may cause significant variation in larval mortality within and among trees. The object of this experiment was to determine the effects of prolonged exposure to constant low temperatures on the survival of cold-hardened larvae within the host in relation to some host characteristics and stage of larval development.

## MATERIALS AND METHODS

The infested lodgepole pine logs used in the experiments were cut at Elk Creek, 40 km east of Canal Flats, British Columbia, during late October 1970. The logs, 40-45 cm long, were moved to the laboratory in Calgary, Alberta, and put into cold storage at -6.6 (± 2.2) °C until 10 January, 1970, when they were moved to the Northern Forestry Centre, Alberta, and stored at -12.2 (± 2.2) °C until used in the experiments.

At the start of the experiments, the logs were cut to 30 cm lengths, waxed at the ends to retard moisture loss, and randomly assigned to treatments. The temperature treatments were -17.8, -23.3, -28.8 and -34.4 °C (0, -10, -20, -30 °F) and control. Temperature treatments were applied in a freezer unit with a minimum temperature limit of -36.1 °C (-33 °F). The control treatment consisted of logs stored at -12.2 °C. The original design called for two bolts to be used at each temperature and duration combination, but lack of suitable material forced us to cut back to single bolts in some treatments (Table 1).

**Table 1**

Number of logs used in the mountain pine beetle low temperature mortality experiments.

| Duration (Days) | Temperature (°C) | | | | |
|---|---|---|---|---|---|
| | -12.2 | -17.8 | -23.3 | -28.8 | -34.4 |
| 1 | 2 | 2 | 2 | 2* | 2 |
| 2 | 2 | 2 | 2 | 2 | 2 |
| 4 | 2 | 2* | 2 | 2 | 2 |
| 8 | 1 | 1 | 1 | 1 | 1 |
| 16 | 1 | 1* | 1 | 1 | 2 |
| 32 | 1 | 1* | 1 | 1 | 1 |

* Denotes a single log containing fewer than five larvae which was dropped from the data analysis.

The treatments were carried out during February and March, 1971. Following treatment, the logs were stored at 1.7 °C (+35 °F) for 1 to 2 days and then at 21.1 °C (+70 °F) for 3 to 7 days prior to inspection for brood survival. Prior to removal of the bark, log diameter (to the nearest 2.5 mm) and bark thickness were measured; the latter on four sides of the log to the nearest 0.8 mm. Moisture content of the outer sapwood to a depth of about 5 years growth was measured on 10.2 cm x 2.5 cm blocks of wood from each of four sides and expressing moisture content as percent oven dry weight (Reid 1961). The numbers of attacks and the total length of the successful egg galleries (those having produced larvae) were determined for each log and converted to a per square meter basis prior to analysis.

The bark was carefully removed and all larvae were placed in Petri dishes on moist filter paper. Obviously living larvae, as shown by movement upon gentle prodding with a probe, were separated, their head capsule widths measured to determine larval instar (Reid 1962; Amman and Cole 1985) using an ocular micrometer on a dissecting microscope, and separated into two groups: large larvae (3rd- and 4th-instar) and small larvae (1st- and 2nd-instar). Non-moving, but non-discoloured and firm larvae were kept at room temperature for a further 24 hours prior to re-assessment for survival and determination of larval size group as described above.

Only logs containing at least five larvae were used in analyses. For this reason, one log treated at -17.8 °C for each of 4, 16 and 32 days and one log treated at -28.8 °C for one day were not used in subsequent analyses. The data were analyzed using correlation and regression analyses, and analysis of variance. The correlation analyses focused on percentage survival by larval size group and log and attack characteristics. The analysis of

variance determined the effects and interactions of temperature and duration of exposure on larval survival. Owing to the lack of replication in some combinations of temperature x treatment duration, we used a general linear model ANOVA (Proc GLM, SAS Institute, 1985) and means were compared by averaging over all levels of the other treatments. Multiple regression analysis was used to predict larval survival in terms of treatment, log, and attack variables.

# RESULTS

The means (± SD), minima and maxima of the log measurements and attacks, egg gallery lengths and brood densities are given in Table 2. Among the log measurements, percent sapwood moisture content was the most variable. Sapwood moisture content ranged from 30% to 118% in individual logs. Among the attack variables, brood density was the most variable and ranged from about 60 to over 2000 per $m^2$. On average, 56.8 % of the brood were in the $3^{rd}$- and $4^{th}$-instars; no pupae or brood adults were present in the logs.

**Table 2**

Means (± SD), minima and maxima of mountain pine beetle attack variables and lodgepole pine log characteristics ($N$=42).

| Variable | Mean | Minimum | Maximum |
|---|---|---|---|
| Log diameter (cm) | 24.8 (2.46) | 15.2 | 27.4 |
| % Sapwood moisture | 61.5 (22.9) | 30 | 118 |
| Bark thickness (mm) | 4.9 (1.04) | 3.2 | 8.3 |
| Attacks per $m^2$ | 141.6 (60.68) | 9.7 | 261.4 |
| Brood per $m^2$ | 896.9 (508.9) | 62.4 | 2005.7 |
| Gallery length (m/m$^2$) | 18.1 (7.70) | 2.6 | 2.7 |

**Table 3**

Pearson correlation matrix of mountain pine beetle attack variables and characteristics of lodgepole pine logs used in the study ($N$=42). Correlation coefficients marked by * and ** are significant at $p{\leq}0.05$ and $p{\leq}0.01$, respectively.

| | Diameter | % Moisture | Bark Thickness (mm) | Attack per m$^2$ | Gallery per m$^2$ | Brood per m$^2$ | % Mortality Small Larvae | % Mortality Large Larvae |
|---|---|---|---|---|---|---|---|---|
| Diameter | 1 | 0.41** | 0.37* | 0.47** | 0.69** | 0.53** | -0.37** | -0.45** |
| % Moisture[a] | | 1 | -0.1 | -0.06 | 0.43** | 0.14 | -0.14 | -0.29 |
| Bark Thickness[a] | | | 1 | 0.85** | 0.60** | 0.42** | 0.02 | -0.07 |
| Attack | | | | 1 | 0.74** | 0.56** | -0.01 | 0.03 |
| Gallery | | | | | 1 | 0.75** | -0.18 | -0.1 |
| Brood | | | | | | 1 | -0.21 | -0.16 |
| % Small | | | | | | | 1 | 0.916** |
| % Large | | | | | | | | 1 |

[a] Four samples per log.

The simple correlation coefficients of all combinations of the log and brood variables are given in Table 3. Log diameter was positively and significantly correlated with each of bark thickness, sapwood moisture content, egg gallery length per $m^2$, attack density and brood density. Bark thickness was positively and significantly correlated with each of the attack variables but sapwood moisture content was significantly correlated with egg

gallery length density only. Brood density was positively and significantly correlated with both attack density and egg gallery length density; the latter two variables were also significantly correlated.

Mortality of the small and large larvae was highly correlated ($r=0.916$, $p<0.01$, $n=42$). The relationship between percent mortality in large larvae (Y) and that of small larvae (X) was linear at all combinations of temperature and exposure duration (Fig. 1). Both the regression coefficient and the intercept were significantly different from zero ($p<0.01$, $n=42$).
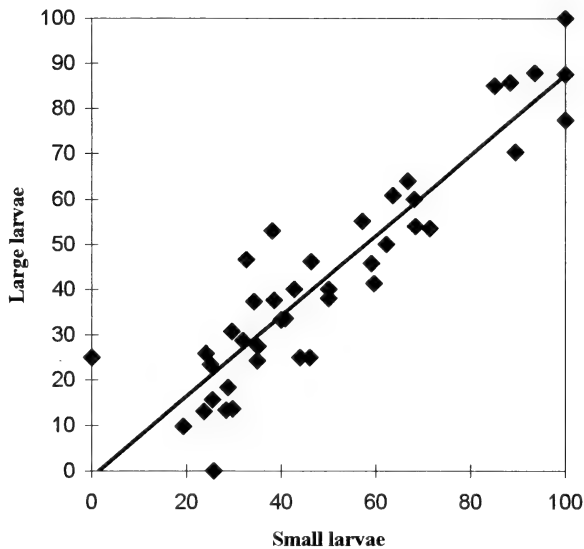


**Figure 1**. The relationship between percent mortality of large (3rd- and 4th-instar)(Y) and small (1st- and 2nd-instar)(X) larvae. The solid line represents the least squares equation: Y=-1.362+0.886X.

Analysis of variance of the combined data for small and large larvae indicated that the temperature treatment, the stage of larval development, and the interactions of stage with temperature and duration of treatment significantly affected mortality. Stage ($F_{1,15}$ = 28.91, $p<0.0001$) and temperature ($F_{4,13}$ = 13.16, $p<0.001$) had the greatest effect followed by the interaction of larval stage with temperature ($F_{4, 15}$=3.36, $p<0.05$) and duration of exposure ($F_{6,15}$=2.98, $p<0.05$).

Percent mortality due to the temperature treatments, averaged over duration of exposure, is given in Table 4. Average percent mortality of the combined larval instars at the coldest temperature was significantly greater than mortality at the other temperature treatments. Average percent mortality at each of -28.8 and -23.3 °C was significantly different from morality at each of -12.2 and -17.8 °C but not within either of these two treatment groups. The patterns of average percent mortality of small and large larvae with respect to temperature treatments were similar except that small larvae suffered greater mortality at all levels of temperature treatment (Table 4).

Percent mortality by duration of temperature exposure, averaged over temperature treatment, is given in Table 5. Larvae in the control logs suffered 27.4% average mortality (21.8% and 32.9% for small and large larvae, respectively), which was significantly lower

than any other treatment. Average percent mortality at each of 1 to 8 days of exposure differed significantly from those at 16 and 32 days of exposure but not within the respective groups. There were no differences in mortality in the controls over the duration of the experiments (Chi-square, 2df = 4.34, $p > 0.05$). In general, the pattern of mortality for small larvae over duration of exposure was the same as overall larval mortality. For large larvae, mortality at each of 4 to 32 day exposures was significantly different from the control and the 1 day exposure (Table 5). There were no significant differences in mortality among exposures of 4 to 32 days.

## Table 4

Percent mortality of small (1$^{st}$- and 2$^{nd}$-instar) and large (3$^{rd}$- and 4$^{th}$-instar) mountain pine beetle larvae maintained at different low temperatures, averaged over duration of exposure. The sample size ($N$) is the number of logs per temperature treatment.

| Temperature (°C) | N | % Mortality | | |
| | | Small larvae | Large larvae | Combined |
|---|---|---|---|---|
| -12.2 | 9 | 32.90 ab | 21.80 a | 27.40 a |
| -17.8 | 6 | 29.65 a | 24.57 a | 27.11 a |
| -23.3 | 9 | 48.34 b | 39.06 b | 43.70 b |
| -28.8 | 8 | 43.67 ab | 43.55 b | 43.61 b |
| -34.4 | 10 | 83.93 c | 75.86 c | 79.89 c |

*Means followed by the same letter within columns are not significantly different ($p > 0.05$, Duncan's Test).

## Table 5

Percent mortality of small (1$^{st}$- and 2$^{nd}$-instar) and large (3$^{rd}$- and 4$^{th}$-instar) mountain pine beetle larvae, at different duration of low temperature exposure, averaged over temperature treatments. The sample size ($N$) is the number of logs per temperature treatment.

| Duration (days) | $N$ | % Mortality | | |
| | | Small larvae | Large larva | Combined |
|---|---|---|---|---|
| 0 | 9 | 32.90 a | 21.80 a | 27.35 a |
| 1 | 7 | 49.79 ab | 44.16 a | 46.97 b |
| 2 | 8 | 45.83 a | 43.39 ab | 44.61 b |
| 4 | 7 | 50.09 ab | 46.21 b | 48.15 b |
| 8 | 4 | 50.95 ab | 43.85 ab | 47.40 b |
| 16 | 4 | 80.13 c | 66.28 b | 73.20 c |
| 32 | 3 | 70.57 c | 61.90 b | 66.23 c |

*Means followed by the same letter within columns are not significantly different ($p > 0.05$, Duncan's Test). Zero duration of exposure indicates the control treatment.

The average percent mortality, taken over temperature treatment and duration of temperature exposure, was 50.0% for small larvae, and 42.9% for large larvae, which were significantly different ($p < 0.001$).

A multiple regression of percent larval mortality of small ($Y_1$) and large ($Y_2$) larvae on log diameter ($X_1$), duration of temperature exposure ($X_2$), temperature treatment ($X_3$) had the following form:

$$Y_1 = 91.55 - 5.71X_1 + 0.87X_2 - 10.88X_3 + 4.90X_3{}^2; R^2 = 0.68, N = 42$$
$$Y_2 = 88.40 - 6.76X_1 + 0.55X_2 + 2.68X_3{}^2; R^2 = 0.76, N = 42$$

All coefficients of both regressions were significantly different from 0 ($p \leq 0.05$). The variable X3 was coded as 0, 1, 2, 3, and 4 in order of decreasing temperature treatment.

# DISCUSSION

The pre-treatment cold storage of the logs was sufficient to induce maximum cold hardiness in the larvae, as they required only about 2 weeks of exposure at -5 °C constant to attain maximum accumulation of glycerol in the blood (Somme 1964). The relatively large variation in percent mortality in the control logs (C.V.=43.2 %) indicates that log characteristics had a large effect.

The strong negative correlation of log diameter with percent brood mortality is explained in part by the high negative correlation of log diameter with temperature treatment ($r$=-0.28), in spite of the random allocation of logs to treatments. Temperature was the single most important variable relating to larval mortality. Log diameter directly affects the rate of cooling, due to the increase with mass in the amount of heat stored. Log diameter was significantly and positively correlated with bark thickness, percent sapwood moisture and attack, brood, and egg gallery length per m$^2$. As bark is a good insulator, its thickness likely reduced heat loss and the rate of cooling of the log. By creating air pockets in the inner bark, attack, brood and egg gallery length densities had similar effects. It is more difficult to assess the effect of sapwood moisture because the thermal conductivity and the specific heat of wood both increase directly with moisture content, hence, though heat may be gained or lost more readily, at a given ambient temperature more heat is stored in wood having a high moisture content.

On average, duration of temperature treatment had only a moderate effect on brood mortality. For both small and large larvae, the greatest daily change in mortality occurred following one day of exposure (Table 5). This is consistent with results by Somme (1964) and Wygant (1940) who showed that the effects of low temperature mortality usually occur within the first few hours of direct exposure. The inconsistent change in mean percent mortality with the duration of exposure in this study is likely due to the unequal replication and large variability among logs discussed above.

Mean percent mortality was the same for the control (-12.2 °C) and the -17.8 °C temperature treatments because cold-hardened larvae could withstand sustained temperatures of these magnitudes (Table 4). For both small and large larvae, the largest change in mortality occurred in the treatment range from -23.3 °C to -34.4 °C. The maximum super cooling point of mountain pine beetle larvae is close to -34 °C (Somme 1964). Some beetles survived even the 32 day exposure at the coldest temperature treatment, probably due to a combination of the moderating effects of log size and bark thickness, and much lower than average individual super cooling points. Since underbark temperatures were not monitored, no information is available on average temperatures and their variability in the inner bark region.

The multiple regressions predicting average percent larval mortality as a function of log diameter, larval size, temperature, and exposure, show that a large proportion of the variation in mortality can be explained by a combination of these variables. Such predictive equations have considerable utility in modeling population dynamics as well as in bark beetle management. Development of such equations should be based on well-replicated experiments that take into account the possible regional variation in cold hardiness.

These results indicate that host characteristics (such as size, bark thickness, and moisture content) and beetle variables (such as attack, egg gallery and brood densities) moderate the effects of low temperatures on mountain pine beetle survival. Mortality from low temperatures is greater for small larvae than for large larvae and the relationship between small and large larval mortality is linear within the temperature range investigated.

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# Sexual biology of *Pandemis pyrusana* (Lepidoptera: Tortricidae) under laboratory conditions

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## ABSTRACT

Laboratory studies were conducted to characterize some aspects of the sexual biology of *Pandemis pyrusana* Kearfott. Both males and females were sexually active during their first scotophase. Virgin females held at 22°C started calling the first night 4 - 5 hrs into scotophase. Calling by virgin females occurred earlier and continued longer into scotophase after the first night. Mating lasted 3 - 4 hrs and both sexes mated only once per evening. Calling frequency by mated females was lower than for virgins and dropped off sharply after 2 nights. Forty percent of females mated more than once during the 6-day test. Males mated on consecutive scotophases, but the percentage of subsequent copulations passing a spermatophore declined with age. Oviposition occurred throughout a diurnal cycle, but was concentrated during early scotophase. Females laid an average of four egg masses from which 219 larvae eclosed. Egg mass size, number of larvae emerging, and the number of larvae emerging per egg mass area declined with subsequent egg masses.

**Key words**: *Pandemis*, leafrollers, apple, sexual behaviour

The pest status of the tortricid moth, *Pandemis pyrusana* Kearfott (PLR) in apple orchards in Washington has increased during the past 15 years (Brunner 1983), especially following the adoption of mating disruption for codling moth, *Cydia pomonella* (L.) and the resultant decrease in use of the broad spectrum organophosphate insecticides (Brunner *et al.* 1994; Knight 1995). PLR have two generations in central WA and overwinters as diapausing second- and third-instar larvae in bark crevices (Brunner and Beers 1996). The first flight begins in late May and the second flight peaks in late August. Control of PLR in tree fruit production has typically been with organophosphate insecticides, although the use of *Bacillus thuringiensis* Berliner has increased recently (Washington Department of Agriculture 1995, Knight 1997). To conserve biological control agents of secondary pests, such as leafhoppers, aphids, and leafminers in orchards treated with sex pheromones for mating disruption of codling moth (Knight 1995), similar non-disruptive approaches like mating disruption are needed for PLR and other leafroller species (Alway 1996).

Knowledge of the sexual behaviour of PLR is a prerequisite for development of mating disruption as an effective management tactic (McNeil 1991). The sex pheromone of PLR is a 94:6 blend of (Z)-11-tetradecenyl acetate and (Z)-9-tetradecenyl acetate (Roelofs *et al.* 1977). Traps baited with sex pheromone lures are used to monitor populations of PLR (Madsen *et al.* 1984) and to time insecticide sprays (Brunner and Beers 1996). Knight *et al.* (1994) used a pheromone-baited timing trap in the field and an ultrasound motion detector in the laboratory to determine the circadian periodicity of PLR moth activity. Other important aspects of PLR adult sexual behavioural ecology, such as temporal patterns of calling, mating, and oviposition and the influence of mating status on these behaviours have not been reported. This paper reports results from laboratory studies with PLR to characterize these aspects of its sexual behaviour.

## MATERIALS AND METHODS

A laboratory colony of PLR was established with larvae collected from several apple orchards in Yakima County, WA in 1992, and larvae have been added to the colony from additional

orchards each year. Larvae were reared on a synthetic pinto bean diet (Shorey and Hale 1965) at 24°C and a 16:8 (L:D) photoperiod in 30 ml plastic cups. Adults were supplied with a cotton wick saturated with a 10% honey solution. Adult sexual behaviours were studied at 22 ± 2°C, 50 - 65% relative humidity, and a 16:8 (L:D) photoperiod. A reversed photoperiod was used to facilitate observations of moth behaviour (lights on at 0900 hr and off at 1700 hrs). Light levels were controlled by time clocks which switched off and on a series of incandescent light sources during the 60 min dusk (0800-0900 h) and sunrise (1700-1800 h) periods (Knight *et al.* 1994). Illumination during scotophase was provided by a light covered with a red acetate filter.

**Calling behaviour**. The effect of mating on female calling behaviour was studied by recording the occurrence of calling of 50 newly-mated and 50 virgin females for 30 sec every 30 min for 5 and 6 nights, respectively. Presumed mated females were dissected at the end of the test to confirm their mating status and only the data for mated females were used. All female moths were < 24h-old at the start of the experiment. Moths to be mated were placed with a virgin 2-day-old male for 24 h. Observations of female calling behaviour were made for moths kept in 250 ml waxed paper cups covered with a clear polyethylene film. Calling behaviour was characterized by wing elevation (up to 45°) and a downward extension of the abdomen. Calling frequency (the number of 30-min intervals during which calling was observed in each scotophase) for mated and virgin females was transformed (square root $[x + 0.01]$) and subjected to analysis of variance (ANOVA) using age as a repeated measure (SAS Institute 1985). If the age-by-mating-status interaction proved to be significant, a one-way ANOVA was used to compare treatments (mating status) for each age separately.

**Mating behaviour**. To test whether males and females mated more than once, 80 virgin pairs (< 24 h-old) were placed in cups during photophase, and males were replaced with a virgin male (< 48 h-old ) in half of the cups and females were replaced with virgin females (< 24 h-old) in the other half each day for 6 days. Moths were observed every 30 min during scotophase to determine their mating status. Females from both sets of cups were dissected after the test to determine whether one or more spermatophores had been passed. Previous dissections of 500 females following a single mating episode did not find more than 1 spermatophore (unpubl. data). Therefore, the number of spermatophores dissected from a female was considered to be equivalent to the number of copulations. The success of males passing a spermatophore as a function of age (number of previous matings) was analyzed with regression analysis using the data from the second set of cups.

**Oviposition**. Oviposition was studied by pairing 30 virgin male and females for 24 h in cups. Egg masses were collected sequentially and placed in cups until egg hatch was completed. The number of larvae eclosing from each egg mass was counted and the area of each egg mass was measured with a LI-3000 portable area meter (LI-COR, Lincoln, NE). Regressions were fitted to determine the relationship between egg mass sequence (i.e., number of egg masses previously deposited by a female) and egg mass area, numbers of larvae hatching, and numbers of larvae hatching per egg mass area. Temporal patterns of oviposition on a wax paper substrate were measured for 50 mated females using a clock-driven rotating oviposition apparatus at 20°C and a 16:8 (L:D) with lights-off at 2200 h (Knight 1996). Newly emerged females were placed in cups with a male (< 24 h-old) for 24 h and females were transferred to the apparatus between 1000-1100 hours. Oviposition was measured for 4 nights.

# RESULTS

**Calling behaviour**. Female calling occurred throughout the entire scotophase. However, virgin females started calling during the first evening on average 4.5 h into scotophase (Fig. 1a, 1b) and continued to call for 1- 2 h. Both the start and the duration of calling by virgin moths was significantly affected by moth age: $F = 5.2$; df = 5, 235; $P < 0.001$ and $F = 7.0$; df = 5, 258; $P <$

0.0001, respectively. Older virgin moths started calling earlier (Fig. 1a) and called longer (Fig. 1b) than younger virgin moths. No differences in calling were found for moths 2 - 6 d-old. Initiation of calling during scotophase was not different between mated and virgin females ($F =$
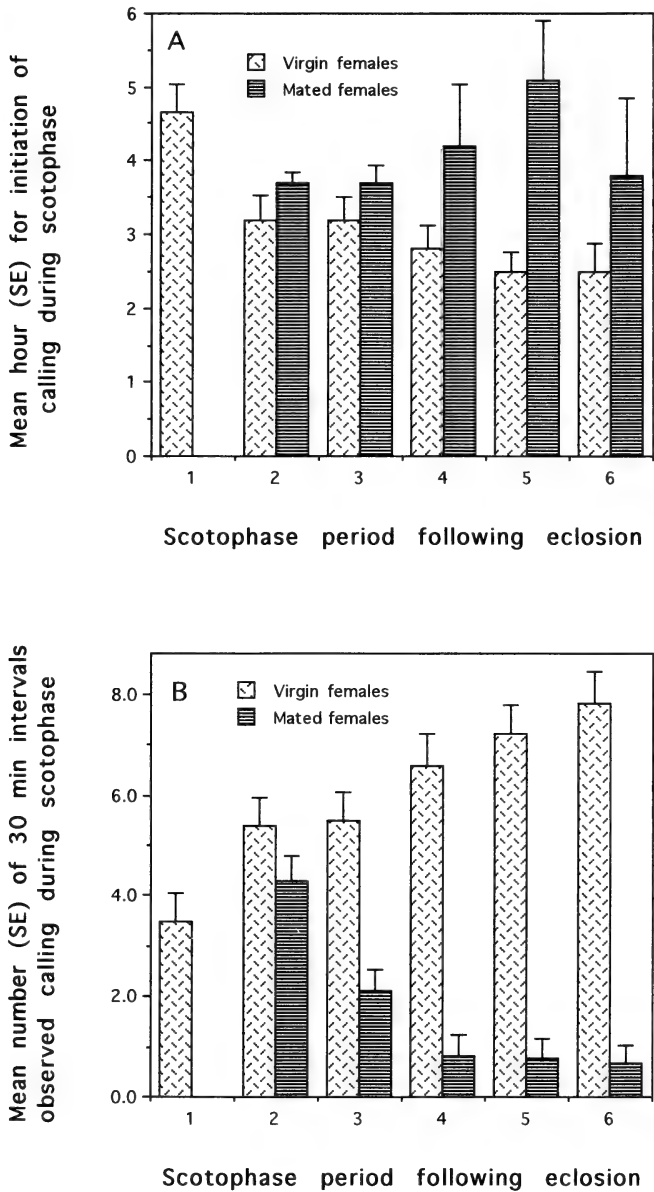


**Figure 1.** Mean hour during an 8-h scotophase that virgin and mated *Pandemis pyrusana* females initiated calling (A) and the mean number of 30 min intervals during scotophase that virgin and mated females were observed calling during a 30 sec observational period (B). Data were collected for 6 consecutive nights after eclosion. Mated females were mated during the first scotophase period and data are shown for periods 2 - 6 only. Error bars are mean standard errors.

2.72; df = 1, 32; $P = 0.11$), and did not vary with respect to age ($F = 0.38$; df = 4, 128; $P = 0.82$)(Fig. 1a.). However, the frequency of calling by mated females was significantly lower than for virgin moths across the five nights ($F = 175.9$; df = 1,70; $P < 0.001$). Calling by mated females was significantly affected by age ($F = 13.6$; df = 4, 135; $P < 0.001$). Mated females significantly decreased their calling on each of the first 2 nights after mating and then called infrequently for the last 3 nights of the test (Fig. 1b).

**Mating behaviour**. Eighty-six percent of females mated when paired with a male moth for 24 h. Forty-four percent of these females mated more than once during the 6 nights when presented with a new virgin male each scotophase. However, only 64% of the females observed mating more than once contained two spermatophores. Females had a mean refractory period of $2.2 \pm 0.3$ days before mating again. Mating began a mean ($\pm$ SE) of $4.1 \pm 0.3$ h into scotophase and lasted for $4.2 \pm 0.3$ h. Thus, both males and females mated only once during the 8 h scotophase. A high percentage of moths were *in copula* at the end of scotophase. Following lights-on, these pairings generally ended. Eighty-three percent of the males mated on each of the 6 nights when paired with a virgin female. However, the proportion of male moths successfully passing a spermatophore during copulation (**y**) was significantly affected by the number of previous matings (**x**):

Equation 1: $\mathbf{y = 1.42 - 0.61x + 0.08x^2}$ ($R^2 = 0.99, P = 0.01$).

**Oviposition**. Egg masses were typically laid within 24 h after mating occurred. Females laid (one to six) egg masses and averaged $4.1 \pm 0.2$ egg masses over the 5-day test. The mean number of eggs hatching per female was $219.0 \pm 12.2$. Nearly 90% of egg masses were laid during scotophase with the mean time of oviposition occurring at $1.9 \pm 0.3$ h into scotophase. The order of egg mass deposition negatively affected ($P < 0.05$) the mean egg mass size, the number of larvae that successfully eclosed, and the number of larvae eclosing per egg mass area (Table 1).

**Table 1**

Regression analysis of mean egg mass size ($mm^2$), the number of larvae eclosing, and the hatching rate (larvae per $mm^2$) as a function of egg mass order for *Pandemis pyrusana* under laboratory conditions at 22°C, 16:8 L:D.

| Egg mass order | No. of egg masses | Mean area (SE) of egg mass ($mm^2$) | Mean no. of larvae hatching | Mean no. of larvae per $mm^2$ |
|---|---|---|---|---|
| 1 | 27 | 13.8 (0.8) | 102.4 (5.9) | 7.5 (0.2) |
| 2 | 26 | 9.7 (0.8) | 78.0 (6.5) | 7.9 (0.4) |
| 3 | 24 | 8.0 (0.6) | 32.3 (7.2) | 3.7 (0.8) |
| 4 | 21 | 5.7 (0.6) | 11.8 (6.1) | 1.8 (0.8) |
| 5 | 11 | 4.3 (0.7) | 10.9 (7.4) | 3.7 (1.3) |
| 6 | 2 | 2.3 (0.7) | 0.0 (0.0) | 0.0 (0.0) |
| | | | | |
| Slope (SE) | | -2.37 (0.25) | -25.97 (3.67) | -1.72 (0.22) |
| *P*-value | | < 0.001 | <0.001 | <0.001 |
| $R^2$ | | 0.45 | 0.55 | 0.36 |

# DISCUSSION

During the past 8 years we have been developing the use of sex-pheromone-based mating disruption as a selective, non-insecticidal approach to manage a suite of tortricid species injurious to tree fruits in the western USA, such as codling moth   (Knight 1995), orange tortrix,

*Argyrotaenia citrana* (Fernald), (Knight 1996), obliquebanded leafroller, *Choristoneura rosaceana* Harris, (Knight *et al.* 1998), and PLR. Successful incorporation of mating disruption technology into tree fruit pest management programs requires a basic knowledge of these insects' biology and behaviour (McNeil 1991). Knight *et al.* (1994) studied the temporal aspects of male and female activity for all four species. More detailed studies of these species' sexual behaviours have been reported for codling moth (see Howell 1991 for a review), orange tortrix (Knight 1996), and obliquebanded leafroller (Delisle 1992, 1995). This paper reports similar information on the temporal aspects of female calling, mating, and oviposition of PLR.

Crop protection using mating disruption for PLR may be difficult to achieve in orchards due to a number of biological factors that include the occurrence of high population densities in orchards and the potential for immigration from other orchards and alternative hosts (Brunner 1983, 1993). The behavioural ecology of PLR also likely limits the success of using sex pheromones for mating disruption. For example, moths are sexually active following emergence, call over a broad time period, can lay a large number of eggs following a single mating, resume calling after mating, and will remate. These behaviours of PLR, as well as similar behaviours reported for other tortricid pest species are highly adaptive and robust to ensure mating success. For example, as virgin *C. rosaceana* age they initiate calling earlier and call more frequently as they age (Delisle 1992; Fig. 1). The initiation and duration of sexual activity of many tortricids can be shifted in response to temperature fluctuations to increase mating success (reviewed in McNeil 1991 ). Low temperatures can shift the calling periodicity earlier and moths that normally call only during scotophase may initiate calling under normally inhibitory high light intensities (*C. rosaceana*: Delisle 1992; *C. pomonella*: Castrovillo and Cardé 1979).

The presence of conspecific sex pheromone can also affect moth behaviour. Weissling and Knight (1996) found that while the temporal patterns of calling and oviposition by *C. pomonella* were unaffected by the presence or absence of its sex pheromone, the frequency of calling by virgin females was significantly higher in codlemone-permeated air than clean air. A similar increase in calling in the presence of its own sex pheromone was reported with the tortricid, *Choristoneura fumiferana* (Clemens) (Palaniswamy and Seabrook 1985). Shifts in the calling periodicity in the presence of its own sex pheromone have been reported for *C. fumiferana* (Palaniswamy and Seabrook 1985) and the tea leafroller *Adoxophyes* sp. (Noguchi and Tamaki 1985).

These examples of the behavioural plasticity of some tortricids suggest that the advantage of employing mechanical 'smart' pheromone dispensers (Shorey *et al.* 1996) that could be turned on at a certain time in response to a specific light intensity threshold, or in relation to a specific temperature may be minor. Successful implementation of sex-pheromone-based mating disruption will occur in situations where constraints imposed by the pest's population dynamics, mating system, and management are minimized (Cardé and Minks 1995). Complete spatial and temporal flooding of the treated habitat with the selected semiochemical is most likely the best approach for maximizing mating disruption. Further studies of moth behaviour in the presence of their sex pheromones and antagonists, clarification of the mechanisms of mating disruption under different application systems, and a more complete knowledge of the role of minor sex pheromone components are three important avenues for future research.

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# Effects of baiting lodgepole pines naturally attacked by the mountain pine beetle with *Ips pini* (Coleoptera: Scolytidae) pheromone on mountain pine beetle brood production

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## ABSTRACT

Lodgepole pine trees which had been naturally attacked by mountain pine beetle (*Dendroctonus ponderosae* Hopk.) were baited with pine engraver (*Ips pini* Say) pheromone in August and September and the effect on mountain pine beetle brood production was evaluated compared to unbaited controls at four heights. Both bait treatments resulted in significant overall reduction of emerging mountain pine beetles.

**Key words:** Coleoptera, Scolytidae, pheromone, ipsdienol, lanierone

## DISCUSSION

Lodgepole pines (*Pinus contorta var. latifolia* Engelm.) killed by mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopk.) are often subsequently attacked by a number of less aggressive (secondary) species of bark beetles (Hopping 1961; Wood 1982; Amman and Safranyik 1985), such as the pine engraver (PE)(*Ips pini* Say). This creates potential competition for food and living space. In the laboratory, Rankin (1983) demonstrated the potential for reducing MPB brood survival, of inducing attacks by PE. However, Safranyik *et al.* (1996) found that in trees naturally attacked by MPB, the density of induced PE attacks had only a weak negative correlation with MPB survival at breast height (1.3m). They also showed that the vertical gradients of attack densities by the two species are inversely related. Hence, assessment of the overall impact of PE competition on MPB brood production should be done by sampling at several heights on the infested bole. The objective of this work was to assess the effects of induced attacks by PE on MPB survival in lodgepole pine based on sampling at four heights on the infested bole. On naturally infested lodgepole pine, PE attacks were induced using two commercially prepared bubble capsules containing ipsdienol and lanierone (release rate 0.2 mg/day and 0.02 mg/day, respectively at 20°C)(Phero Tech Inc., Delta, BC, Canada) attached to the north side of the bole at breast height. There were three treatments: control (no bait), baited 14 August, and baited 4 September, 1991. Three trees of similar diameter were selected from each treatment from those used in the study of Safranyik *et al.* (1996). On 9 November 1991, after several days of freezing weather, the trees were felled, 40-cm-long logs were removed from four evenly spaced points along the bole of each tree, individually caged, and kept indoors at 20°C until emergence had ceased. Emerged insects were collected 2-3 times weekly. Attack density was determined by removing two 15cm square samples from each log, or by peeling the whole log. All observations were converted to a square meter basis and counts were transformed to $\sqrt{(X + 0.5)}$ prior to analysis. MPB attacks were analyzed by analysis of variance and counts of emerged adults were analyzed by covariance analysis using attack count as the co-variate. Differences among means were tested by multiple comparison procedures using Tukey's test (SAS

1990) at the 5% probability level. Mountain pine beetle attack density varied significantly among the bait treatments ($F_{2,5}$= 12.50, $p$< 0.05)( Table 1). Height effects were also significant ($F_{3,15}$= 6.04, $p$<0.01) as mean attack density decreased with height on the bole (Table 2). This is the usual attack pattern for MPB (Safranyik 1968). There was no

### Table 1

Mean densities (±SE) of attacks and emerged mountain pine beetles by bait treatment averaged over bolt height  (three trees per treatment).

| Bait Treatment per m$^2$ | Attacks per m$^2$ | Emerged Adults |
|---|---|---|
| Control | 62.96 ± 11.23 a | 492.40 ± 102.80 a |
| August | 29.63 ± 6.89  b | 181.20 ± 54.81  b |
| September | 72.21 ± 19.64 a | 250.12 ± 84.18* b |

*Based on 2 trees
Means within columns designated by the same letters are not statistically significant ($p$> 0.05, Tukey's test)

### Table 2

Mean densities (±SE) of attacks and emerged mountain pine beetles by bolt height averaged over bait treatment (total of eight trees sampled).

| Bolt Height(m) per m$^2$ | Attack per m$^2$ | Emerged Adults |
|---|---|---|
| 2 | 91.67 ± 27.01 a | 306.58 ± 135.81 a |
| 8 | 63.89 ± 7.59  ab | 433.76 ± 152.67 a |
| 14 | 38.89 ± 12.29 ab | 276.94 ± 95.49  a |
| 20 | 16.67 ± 11.10 b | 134.34 ± 126.97 a |

Means within columns designated by the same letters are not statistically significant ($p$> 0.05, Tukey's test)

significant interaction between bait treatment and height ($F_{6,15}$= 0.64).   One of the trees selected from the September baited group failed to produce any brood, and was dropped from the data set. Covariance analysis of emerged mountain pine beetle density indicated that overall treatment effect was marginally significant ($F_{2,23}$= 3.45, $p$=0.066) and there was no significant position (height on bole) or position by treatment effect (Table 2). The differences between the control and each of the August and September treatments were significant at $p$<0.05 (Table 1). The co-variate, mountain pine beetle attack density, was significant ($F_{1,17}$ =6.55, $p$=0.02) and explained 11% of the variation in emerged mountain pine beetle density. Although Safranyik et al. (1996) did not find significant differences in MPB attack density at breast height in response to the same bait treatments, our results indicate that PE baits inhibited MPB attacks based on the entire infested bole.   Two factors were responsible for significantly reduced brood production in the August bait treatment (Table 1): reduced final density of MPB attacks; and increased host resistance that occurs at lower attack rates, and results in reduced brood survival.  However, as MPB attacks substantially ceased by the end of August, the reduced MPB brood production in the September bait treatment was likely caused by direct competition for food and space by MPB and PE brood. Safranyik et al (1996) showed that the density of hibernating PE in the duff (an index of overall PE production in the tree) was significantly greater in the September treatment than in the other two treatments. The results of this work suggest that assessments of competitive interactions between bark beetle species should examine brood production over the entire infested bole and control key tree and attack variables.

## ACKNOWLEDGEMENTS

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# Oviposition by sterile codling moths, *Cydia pomonella* (Lepidoptera: Tortricidae) and control of wild populations with combined releases of sterile moths and egg parasitoids

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## ABSTRACT

This paper provides data on the number of nonviable *Cydia pomonella* (L.) eggs that are present in orchards receiving sterile moths and the potential for these eggs to support populations of the parasitoid *Trichogramma platneri* Nagarkatti. In the laboratory, non-irradiated female codling moths laid ca. 214 eggs in their lifetime while females irradiated with 330 Gy laid only 93 eggs. Persistence data collected in the field indicated that the majority of nonviable eggs were no longer suitable for parasitization after 1 week. With a release rate of 1,000 sterile females per hectare per week we estimated that 30,000-40,000 nonviable eggs per hectare would be present in orchards at any given time. When a combination of sterile moths and parasitoids were released into large field-cages fruit damage was less than seen when either tactic was used alone.

**Key words:** *Cydia pomonella*, sterile insect release, oviposition, biological control, parasitoid

## INTRODUCTION

The codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), is the key pest of apples and pears in the Pacific Northwest (Madsen and Procter 1982). Control programs for this pest have traditionally relied on organophosphate insecticides. However, resistance to these chemicals is increasing (Varela *et al.* 1993), as is pressure from environmental and worker safety groups to limit or eliminate the use of pesticides in fruit production (Calkins *et al.* 1998). In response to these pressures, apple pest management in the western USA has focused on the use of sex pheromones to disrupt codling moth mating (Knight 1995). In Washington State, an estimated 15,000-16,000 ha were treated in 1998, up from close to 11,000 ha in 1997. Total area treated with codling moth mating disruption in western North America was ≈24,500 ha in 1998 (Anonymous 1998). In addition, the use of entomopathogens [e.g., bacteria (Knight 1997) and nematodes

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(Warner 1997; Lacey and Chauvin 1998)] and parasitoids is being evaluated for use in combination with mating disruption in areas where high codling moth populations are present, or as supplementary tactics to control secondary orchard pests such as leafrollers (Lepidoptera: Tortricidae) (Lawson *et al.* 1997).

An alternative to mating disruption is the sterile insect technique being implemented in southern British Columbia by the Okanagan-Kootenay Sterile Insect Release (SIR) Program to eradicate the codling moth (Dyck *et al.* 1993; Bloem and Bloem 1998). Insects are mass-reared and sterilized with gamma radiation in Osoyoos, BC, and then released twice per week into ≈3,500 ha of apples and pears in the south Okanagan, Similkameen and Creston Valleys. The SIR Program releases both sterile males and sterile females. In 1996, the release rate was ≈1,000 moths (sex ratio 1:1) per ha twice per week for about 20 weeks from early May to mid-September (Bloem *et al.* 1997). Unlike sterile release programs for fruitflies where released females can injure fruit during oviposition (Franz and Kerremans 1994), releases of sterile codling moth females have no impact on fruit quality and may help to control wild populations by attracting and engaging feral males (White *et al.* 1976).

Knipling (1992) suggested that the synergistic suppression of a pest population is possible when sterile insects and parasites are concurrently released. For control of codling moths, the combined release of sterile insects and *Trichogramma* (Hymenoptera: Trichogrammatidae) egg parasitoids was first suggested by Nagy (1973). Recently, releases of *Trichogramma platneri* Nagarkatti have been used to control lepidopteran pests in avocado (Oatman and Platner 1985) and codling moths in walnut orchards in California (N. Mills, U.C. Berkeley, personal communication). *T. platneri* has also been used to control oblique-banded leafrollers, *Choristoneura rosaceana* (Lepidoptera: Tortricidae) in apple orchards in New York (Lawson *et al.* 1997). In British Columbia, native *T. platneri* have been collected in apple orchards that are currently being treated with sterile codling moths (S. Bloem, unpublished results).

Because matings involving at least one sterile partner result in the production of nonviable eggs, a potentially large number of nonviable eggs could be present in orchards receiving sterile moths (Nagy 1973). Cossentine *et al.* (1996) report that nonviable codling moth eggs are suitable, although sub-optimal, hosts for *T. platneri* in the laboratory. Thus, it is possible that large numbers of nonviable eggs in orchards under sterile moth release might allow the establishment and maintenance of increased numbers of *T. platneri* (Cossentine *et al.* 1996).

In an effort to determine how many nonviable codling moth eggs are being actually laid in orchards under sterile insect release, provide an estimate of the population density of *T. platneri* that might be maintained on these eggs, and evaluate whether concurrent releases of *T. platneri* and sterile moths can improve control of wild codling moth populations over that of sterile moth releases alone, we:

1) collected data on daily and lifetime egg production by sterile females; 2) determined the persistence of nonviable eggs as suitable hosts for *T. platneri* under field conditions; 3) collected data on the number of nonviable eggs found in orchards under sterile moth release and compared these to predicted numbers; and 4) compared the amount of fruit damage that occurred when releases of *T. platneri* and sterile moths were made in large field-cages containing individual apple trees to control a known number of fertile codling moths.

## MATERIALS AND METHODS

**Test Insects.** Adult moths were provided by the codling moth mass-rearing facility in Osoyoos, BC. Shipments of *Trichogramma platneri* were purchased from Rincon-Vitova

Insectaries, Ventura, CA, as developing pupae inside eggs of the Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae).

**Lifetime Egg Production by Colony Females**. Newly emerged (< 24 h) adult codling moths were sorted by sex and either left non-irradiated (N = normal) or irradiated (I) with 330 Gy (Cobalt[60]; Gammacell 220; Nordion Intl. Inc., Canada). Non-irradiated moths were packaged into Petri dishes and set-up as if they were to be irradiated to insure equal handling. Non-irradiated and irradiated moths were then paired into four treatments: N x N, I x I, N x I and I x N, female x male, respectively. Individual pairs were placed in clear 200 ml plastic cups with lids; a moist wick extending through the lid provided moisture and was re-wetted daily. The insects were allowed to mate and lay eggs at 25°C, 16L:8D and 55% RH until the females died. The total number of eggs laid per cup was counted and recorded. Ten pairs of codling moths per treatment per replicate were used and six replicates were completed, three replicates at each of two times. Egg count data were normalized using square root (sqrt [n+0.5]) transformation and subjected to a two-way (time x treatment) analysis of variance followed by a comparison of treatment means using Student-Newman Keuls' (SNK test) multiple range test (SAS 1985).

**Daily Egg Production by Colony Females**. Newly emerged adults were sorted by sex and either left non-irradiated (N) or irradiated (I) as above. Pairs of non-irradiated (N x N) or irradiated (I x I) females and males were placed in clear plastic cups (200 ml) and allowed to mate and lay eggs at 25°C, 16L:8D and 55% RH for 24 hours. The cups were briefly chilled (0-2°C) and the insects transferred to new cups daily for 7 days. The number of eggs laid per day by each female were counted and recorded. Twenty-five pairs of N x N and I x I were used per replicate and three replicates were completed. Egg counts were transformed as above and analyzed with a two-way (day x treatment) analysis of variance, followed by separation of treatment means using Student-Newman Keuls' (SNK) multiple range test.

**Persistence of Nonviable Moth Eggs in the Field**. Two apple orchards, one conventional and one organic in Summerland, BC, were used for this study. Five pairs of irradiated male and female codling moths were liberated into mesh sleeve cages with heavy wire frames (50 by 25 by 25 cm) that were placed over branches in the upper 1/3 of the canopy on five randomly selected trees in each orchard. The insects were allowed to mate and lay eggs in the cages for 72 h after which cages were removed and insects discarded.

The leaves on each branch were examined for the presence of eggs. Leaves with eggs were marked by attaching small plastic tags with wires to the leaf petiole. No fewer than 10 (*n* = 10-22) eggs per branch were tagged. Eggs were checked after 2, 5, 8, 11, and 14 days in both orchards. At each observation, egg status was coded as suitable for parasitization (= egg present and plump) or unsuitable for parasitization (= egg present and flat or egg absent). Field temperatures were monitored with electronic datapods (Kiwi Group, North Falmouth, MA). The experiment was repeated twice, once in early June and again in late July 1996. Persistence of nonviable eggs was compared between conventional and organic orchards and between seasons using analysis of variance.

**Density of Nonviable Eggs in Orchards Receiving Sterile Moths**. Apple leaves in five orchards in Summerland, BC, were examined weekly for 18 weeks (17 May - 20 Sept. 1996) for the presence of codling moth eggs. In mature, traditional plantings of Golden Delicious, Red Delicious, and McIntosh, 1,000 leaves were examined each week - 100 leaves per tree from the upper 1/3 of the tree canopy in 10 randomly selected trees per orchard. Ten apples from each of the 10 trees (*n* = 100 fruit) were also examined each week for eggs. In high density plantings of Fuji and Royal Gala, 50 leaves and five apples per tree were examined at random from the entire tree canopy of 20 trees each week (*n* = 1,000 leaves and 100 fruit).

When an egg was located, the leaf or fruit was collected and taken to the laboratory where it was held at 23°C, 16L:8D and 50% RH for 7 days to determine egg viability. The total number of leaves sampled per variety divided by the total number of eggs found was used to calculate the mean number of leaves required to be sampled in order to find one codling moth egg.

The mean number of leaves per tree (L/T) was estimated using the equation: L/T = $(0.8)(td)^2$, where 0.8 is a constant corresponding to heavy soil type; td is trunk diameter measured in mm (P. Parchomchuk, AAFC-PARC, Summerland BC, personal communication.). Trunk diameter was measured in five trees per variety at random. Spacing between trees was measured and used to determine the number of trees per ha. The expected number of codling moth eggs present was estimated by using the number of leaves per ha per variety, laboratory oviposition rates by irradiated females and field release rates for sterile codling moths (SIR Program, personal communication). We assumed that field oviposition was 50% of that obtained in the laboratory (Howell 1991 and refs. therein), and that 85% of the eggs laid on any given day were gone after 1 week and 100% were gone after 2 weeks (based on egg persistence data).

**Combination of Sterile Insect Release and Egg Parasitoids**. Large polypropylene mesh field-cages (3.65 by 3.65 by 3.65 m) (Chicopee, Gainesville, GA) were used to enclose single Spartan apple trees (mean height = 2.75 m) in an unsprayed orchard in Summerland, BC. All naturally occurring fruit was stripped from the trees. Several hundred thinning apples (3.5-5.0 cm diameter) were collected in mid-June from an unsprayed orchard in Oliver, BC. The fruit was washed, examined for insect damage, and a 30 cm length of cotton string attached to each fruit stem. The apples were then stored in paper bags at 0-2°C until needed. On the morning of the release, 50 apples were hung at random throughout the tree canopy inside each cage.

Shipments of *T. platneri* were stored in the dark at 15°C until prepared for release. On the day prior to release, ≈6,000 parasitized grain moth eggs were placed inside small (1 lb) paper bags; a dental wick soaked in a dilute honey solution (1 honey: 40 $H_2O$) was added to each bag to provide moisture and carbohydrates to emerging parasitoids. Bags were stapled shut and stored in darkness at 25°C until the time of release. A sample of each shipment was kept in the laboratory to verify % adult emergence and sex ratio.

On the morning of the release, non-irradiated (N) and irradiated (I) colony moths were counted, sexed, and placed in Petri dishes according to treatment requirements. Four treatments were randomly assigned to the field-cages: N = check = (five non-irradiated males and females); N + I = (N + 50 irradiated males and females); N + T = (N + one bag with ≈6,000 *T. platneri*); and N + I + T. Moths were transported to the field in a cooler and released into the cages in mid-afternoon (1530 hours [PST]). Moths were released into the cages by placing them into open (1 litre) paper cups hung horizontally at mid-canopy (separate cups were used for N and I moths), which provided a temporary shelter where the moths could warm-up and subsequently disperse. In cages receiving parasitoids, the paper bag was tied to an inner middle branch of the tree and 10-15 exit holes were opened in the bag with a dissecting probe.

Once per week, leaves were examined for developing or parasitized moth eggs, and thinning apples were examined for evidence of larval entries. After 4 weeks, all thinning apples were removed from the trees and held in the laboratory at 23°C, 16L:8D and 50% RH for 7 days. The number of damaged apples and larval entries per apple were recorded. The four treatments were repeated over four time periods with two–four replicates at each time, for a total of 10 replicates. To stabilize the variances, the number of damaged apples per treatment was transformed using arcsine (sqrt[$n/50$]) and the number of larval entries transformed using log 10 ($n+1$). Data were analyzed by a two-way (treatment x time)

analysis of variance, followed by comparison of treatment means using Student-Newman Keuls' (SNK test) multiple range test.

# RESULTS

**Lifetime Egg Production by Colony Females**. Irradiated female codling moths (I) laid 57% fewer eggs than did non-irradiated (N) females ($F = 73.89$, df = 3, 39, $P = 0.0001$). However, the number of eggs laid by N and I females was independent of whether the male mating partner was irradiated or not. Non-irradiated females laid an average of 216.3±8.8 (SE) and 212.2±11.6 when paired with N and I males, respectively. Irradiated females laid an average of 92.5±6.1 and 93.3±8.0 eggs when paired with N and I males, respectively.

**Daily Egg Production by Colony Females**. The daily egg laying schedule was significantly different for I and N females ($F = 36.84$, df = 5, 24, $P = 0.0001$ for day; $F = 9.71$, df = 1, 24, $P = 0.0047$ for treatment) (Fig. 1). A more gradual increase in egg deposition was observed in I females, who by day 3 had laid only 58% of their total eggs, as compared to 84% for N females. By day 4, I and N females had laid 82.4% and 94.3% of total eggs, respectively. However, the greatest number of eggs was laid on day 2 after mating by both I and N females. The total number of eggs laid by I females in this experiment was similar to that recorded in the previous experiment, even though females were subjected to more handling (i.e., chilled and transferred to new oviposition cups every 24 h). This was not true for N females, which showed a 39% decrease in oviposition when handled daily.
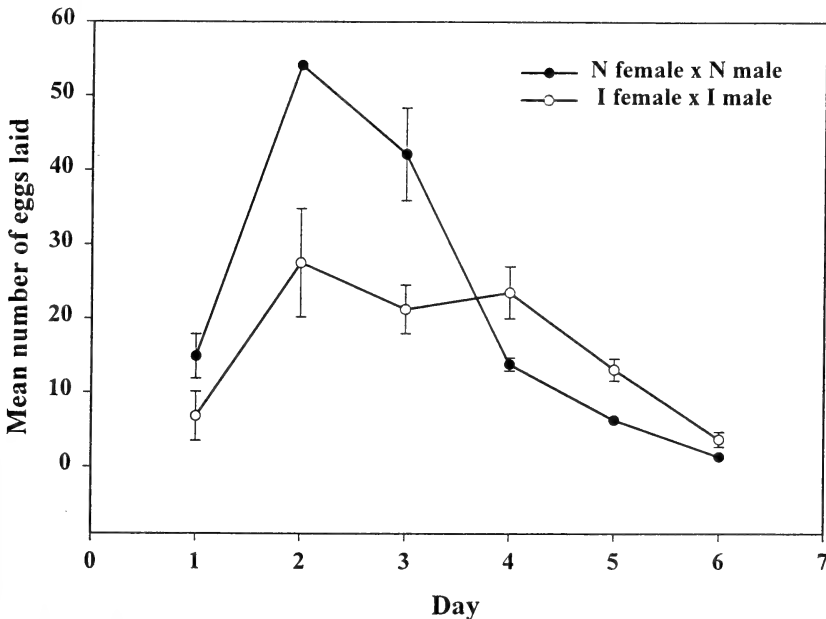


**Figure 1**. Mean number of eggs (±SE) deposited per day by *Cydia pomonella* females ($n = 75$) in the laboratory. Females and males were either non-irradiated (N x N) or treated with 330 Gy of gamma radiation (I x I). Points with missing SE bars have SE's smaller than the point.

**Persistence of Nonviable Moth Eggs in the Field**. No significant difference was found in the persistence of codling moths eggs laid by irradiated females in organic

versus conventional apple orchards ($F = 3.13$, df = 1, 16, $P = 0.3715$); however, egg persistence was significantly shorter in both orchards in July than it was in June ($F = 42.5$, df = 3, 16, P = 0.0001) (Table 1). In June, 20-25% of the eggs laid appeared fresh and suitable for parasitization by *T. platneri* after 1 week and 7-10% appeared fresh after 2 weeks. In July, when daily temperatures were warmer, only 5-6% of the eggs still appeared to be suitable for parasitism after 1 week and < 5% were suitable after 2 weeks (mean daily maximum temperatures were 26.3°C and 32.0°C in June and July, respectively).

**Table 1**

Persistence of nonviable *Cydia pomonella* eggs laid by sterile females on the foliage of apple trees in orchards in Summerland, BC, during June and July, 1996.

| | % of Eggs Suitable for Parasitism [a] | | | |
| --- | --- | --- | --- | --- |
| | June | | July | |
| Days After Oviposition | Organic Orchard ($n$=100) | Conventional Orchard ($n$=75) | Organic Orchard ($n$=102) | Conventional Orchard ($n$=98) |
| 2 | 81.0 a | 98.7 a | 71.6 a | 83.7 a |
| 5 | 34.0 b | 53.3 b | 15.7 b | 28.6 b |
| 8 | 20.0 b | 22.7 c | 5.9 c | 5.1 c |
| 11 | -- [b] | 12.0 d | 5.9 c | -- [c] |
| 14 | 10.0 c | 6.7 e | 3.9 c | 3.1 c |

[a] Mean percentages within a column followed by the same letters are not significantly different ($P > 0.05$).
[b] Bees swarming in the orchard prevented data collection.
[c] An application of endosulfan prevented entry into the orchard.

**Density of Nonviable Eggs in Orchards Receiving Sterile Moths**. Sterile codling moths were first released on 24 April 1996, and weekly sampling for eggs occurred from 17 May-20 Sept. 1996. The first egg was found on 21 June, on a McIntosh apple leaf. After this date, eggs were consistently found each week, with the number of eggs per apple variety ranging from 1-10 in 1,000 leaves. No eggs were ever found on fruit. Also, no embryonic development was ever observed after incubation in the laboratory, suggesting that all eggs found were laid by sterile females or by wild females that had mated with sterile males. The total number of eggs collected per apple variety in the 18-week sampling period was 19 in Red Delicious, 9 in Golden Delicious, 26 in McIntosh, 11 in Royal Gala, and 25 in Fuji.

As shown in Table 2, the number of codling moth eggs found per week was 2-3 times greater than the number we expected to find in the traditional apple orchards (Red Delicious, Golden Delicious, and McIntosh) based on the number of leaves per ha, the number of released sterile moths, and oviposition and persistence data. In contrast, the actual number of eggs found in the high density orchards (Royal Gala and Fuji) during our leaf sampling was about 40% less than expected.

**Combination of Sterile Insect Release and Egg Parasitoids**. There was a significant reduction in the proportion of damaged apples and the number of larval entries per treatment when irradiated codling moths (I), parasitoids (T), or both were added to the field-cages containing fertile codling moths ($F = 12.4$, df = 3, 24, $P = 0.0001$ for apples; $F = 15.0$, df = 3, 24, $P = 0.0001$ for larval entries) (Table 3). Both treatments reduced the number of damaged fruit by ≈50% and the total number of stings by ≈60%. The effect of simultaneous release of irradiated moths and *T. platneri* parasitoids appears to be additive.

When both treatments were used together the mean number of apples damaged was reduced by almost 84% and the average number of larval entries by ≈90% (Table 3).

**Table 2**

A comparison of expected versus actual number of *Cydia pomonella* eggs found in weekly samples of leaves taken during 17 May - 20 Sept. 1996 from apple orchards in Summerland, BC, under sterile insect release (1,000 leaves per orchard).

| Orchard | Tree spacing (m) | Approx. trees/ ha | Estimated leaves/ tree [a] | Estimated leaves/ ha | Expected eggs/leaf/ week [b] | # eggs found/ leaf/week |
|---------|------------------|-------------------|-----------------------------|----------------------|-------------------------------|--------------------------|
| Red D. | 5.3x3.8 | 490 | 226,600 | 111,034,000 | 1/2,095 | 1/947 |
| Golden D. | 3.7x3.7 | 730 | 310,250 | 226,482,500 | 1/4,273 | 1/2,000 |
| McIntosh | 7.2x3.6 | 390 | 338,000 | 131,820,000 | 1/2,487 | 1/692 |
| Roy. Gala | 2.9x0.5 | 6,800 | 7,400 | 50,320,000 | 1/949 | 1/1,636 |
| Fuji | 3.0x1.3 | 2,500 | 9,400 | 23,500,000 | 1/443 | 1/720 |

[a] Using estimated number of leaves per tree = 0.8 [trunk diameter $(mm)]^2$ provided by P. Parchomchuk, AAFC-PARC, Summerland, BC.
[b] Based on the following assumptions: i) 1,000 females per ha are present each week in orchards receiving sterile moths; ii) all eggs found during sampling were laid by irradiated females; iii) released females lay all of their eggs and then die after 1 week (based on data presented here and in Bloem *et al.* 1998); iv) the number of eggs laid by irradiated females in the field is 50% that recorded in the laboratory; v) 85% of the eggs laid by a given female are gone after 1 week and 100% are gone after 2 weeks.

**Table 3**

Reduction in *Cydia pomonella* damage due to the release of sterile codling moths at a 10:1 overflooding ratio, a single release of *Trichogramma platneri*, or a combination of both tactics in large field-cages containing individual apple trees, Summerland, BC, 1994-1995.

| Treatment [a] | No. Apples Sampled [b] (*n*) | % Damaged Fruit [c] (mean ± SE) | % Reduction due to Treatment | No. Entries in 50 Apples [c] (mean ± SE) |
|----------------|------------------------------|----------------------------------|-------------------------------|-------------------------------------------|
| N | 500 | 32.4 ± 5.4 a | - | 27.7 ± 6.8 a |
| N+I | 500 | 13.4 ± 3.8 b | 58.6 | 8.9 ± 3.2 b |
| N+T | 500 | 18.2 ± 5.8 b | 43.8 | 13.0 ± 4.8 b |
| N+I+T | 500 | 5.2 ± 1.9 c | 83.9 | 2.6 ± 1.0 c |

[a] N = non-irradiated (fertile) codling moths (5 males and 5 females per cage); I = irradiated (330 Gy) moths (50 males and 50 females per cage); T = commercially available *T. platneri* (≈6,000 per cage).
[b] Ten replicates with 50 apples per replicate.
[c] Means within a column followed by the same letters are not significantly different ($P > 0.05$ SNK).

## DISCUSSION

This paper documents the negative impact of gamma radiation on oviposition by codling moth females and provides a measure of the number of nonviable codling moth eggs that are present in orchards receiving sterile moths. It also examines the effect of combining a release of sterile codling moths with a single release of *T. platneri* in large field-cages. Our results showed that the combination of both tactics after 4 weeks

significantly reduced fruit damage caused by fertile codling moths (introduced into the cages) over that obtained when either tactic was used separately.

Data on other codling moth colonies indicates that fecundity per female generally varies between 132-162 eggs (Howell 1991 and refs. therein). However, non-irradiated females from the mass-rearing facility in Osoyoos, BC, were much more fecund that those reported in Howell (1991), producing an average of 214 eggs under laboratory conditions. This higher fecundity may be due to strain differences, better larval nutrition during mass-rearing, better handling of the adults, or a combination of these. Regardless, high fecundity in colony females is beneficial for mass-rearing and suggests that the SIR colony is healthy and vigorous. On average, females treated with 330 Gy laid only 93 eggs. These results support the findings of Proverbs and Newton (1962) and confirm that gamma radiation has a detrimental effect on oviposition. However, unlike results reported by Robinson (1974), the number of eggs laid by females was not affected by whether they mated with irradiated or non-irradiated males. This discrepancy might be explained by again suggesting that the current codling moth colony is more vigorous than the one used by Robinson in 1974, and as such, the negative effect of radiation on the ability of males to transfer sperm to females has been reduced.

It is interesting to note that irradiated females were less affected by handling than were fertile females. The fecundity of irradiated females was similar in both lifetime and daily oviposition experiments, even though in the second test females were moved to a new cup every 24 h. In contrast, non-irradiated females laid approximately 39% fewer eggs when they were transferred daily. The reason why irradiated females failed to show a decrease in oviposition with increased handling is not known, although it has been shown that irradiated moths are longer lived than non-irradiated moths (Proverbs and Newton 1962). It has also been suggested that irradiated insects are generally less active (Proverbs and Newton 1962). This may partially explain why irradiated moths have a lower recapture rate and are less competitive at mating than are non-treated moths (Bloem *et al.* 1998). However, less active insects may also be less affected by handling and thus longer lived in laboratory bioassays. The fact that we observed more gradual egg laying in irradiated females (Fig. 1) may be related to the detrimental effect of radiation on oocyte maturation or on their reduced activity level, or both (Proverbs and Newton 1962).

The SIR Program releases sterile moths for 20 weeks each year at the rate of $\approx$2,000 moths per ha per week. Both males and females are liberated and the sex ratio is consistently 1:1. As such, we can assume that $\approx$1,000 females per ha per week are present in orchards throughout the season. It is reasonable to expect a decrease in oviposition when sterile females are released into the field. Many biotic and abiotic factors will adversely affect egg production. When preparing Table 2, we assumed that released females survived 1 week, most field matings occurred between sterile moths (I x I), oviposition in the field was 50% of laboratory totals, and that all eggs laid remained in the orchard for 1 week and 15% of them persisted for 2 weeks. As such, we might expect $\approx$53,000 eggs per ha at any given time during the release season (i.e., 50% of 93 eggs per I female in the laboratory = 46.5 eggs x 1,000 females = 46,500 eggs laid in any given week + 15% from previous week = $\approx$53,000 eggs/ha/wk). Jackson (1979) found that the upper leaf surface is always preferred for oviposition by wild females followed by lower leaf surface, fruit and stem. Unpublished data (S. Bloem) suggests that irradiated female preferences are no different than those reported by Jackson (1979).

The fact that we found 2-3 times as many codling moth eggs as we expected in the larger trees (Red Delicious, Golden Delicious, and McIntosh) can be explained, in part, by pointing out that our estimates were based on the assumption that eggs are laid randomly throughout the trees (total number of leaves per ha divided by the expected number of eggs laid per ha). In reality, codling moth females have an ovipositional

preference for the upper portions of apple trees. Richardson and Du Chanois (1950) and Wood (1965) report that 65-85% of codling moth eggs are laid in the upper half of the tree canopy depending on tree height. In our experiments, leaf samples were taken from the upper third of the canopy. As such, the number of eggs found per leaf in these varieties really only applies to the portion of the tree sampled and not to the entire tree. The actual number of eggs per leaf is probably lower and closer to the expected number, as found in the samples taken from Royal Gala and Fuji. Thirty thousand to 40,000 nonviable codling moth eggs per ha per week in orchards under sterile release is probably a more accurate estimate than the 53,000 as originally predicted.

Even though the simultaneous release of sterile moths (at a 10:1 overflooding ratio) and *T. platneri* still allowed some fruit damage to occur, the control provided by both tactics was significantly improved over the protection offered by a single tactic. These results suggest that releasing a generalist egg parasitoid might be a reasonable approach to use in combination with sterile moth release under certain conditions or at certain times of the year, particularly if the parasitoids are able to maintain good field populations by utilizing the nonviable eggs being laid by sterile females as replacement host material. However, our experiments were conducted inside large field-cages. As such, the effect of some biotic (e.g., predators) and abiotic (e.g., wind and rain) factors may have been modified. In addition, the cages confined the sterile moths to the vicinity of one tree and artificially concentrated oviposition (at the end of 4 weeks, a sample of 1,200 leaves found 1,163 non-viable eggs or 0.97 eggs per leaf). A concentrated distribution of nonviable eggs might have influenced host finding by the released *T. platneri* females and as a consequence the level of control provided may be different if evaluated under true field conditions.

The commercially recommended release rate for *T. platneri* is 200,000-250,000 per ha per week. This is significantly higher than the population that could be maintained on the 30,000-40,000 nonviable eggs being laid by sterile codling moths. However, the consistent availability of these eggs should support higher than normal parasitoid populations and prevent extinctions which typically occur throughout the growing season when natural host egg densities are low. Because *T. platneri* is a generalist parasitoid the "artificially" maintained populations could be expected to provide some measure of control against other lepidopteran orchard pests. Only a limited number of parasitoid releases may be necessary to establish resident populations, but they should be delayed until mid-June when egg laying by sterile moths occurs.

Although our data suggests that the level of control provided by the combination of tactics was additive it only represents a single generation effect (i.e., 4 weeks). Hence, our results do not rule out a possible synergistic effect which would manifest itself over time (Knipling 1992; Carpenter 1998). With increasing pressure from the urban public to reduce pesticide use and insure the safety of our food supply (e.g., the U. S. Food Quality Protection Act of 1996), growers and scientists are actively searching for tactics or combinations of tactics that satisfy environmental concerns yet remain cost effective (Carpenter 1998). It remains possible that a combination of *T. platneri* with sterile moth releases can improve the efficiency and cost effectiveness over either tactic used alone for codling moth control. Further investigation under actual field conditions would be necessary to determine if and when this occurs.

## ACKNOWLEDGEMENTS

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# Seasonal occurrence and parasitism of *Bucculatrix ainsliella* (Lepidoptera: Lyonetiidae) on *Quercus rubra* in Burnaby, British Columbia

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## ABSTRACT

The seasonal occurrence of life-history stages of *Bucculatrix ainsliella* Murtfeldt (Lepidoptera: Lyonetiidae), and the level of attack by parasitoids on larvae and pupae, were determined for a population occurring on red oak trees (*Quercus rubra* L.) in an urban area of Burnaby, BC. *B. ainsliella* completed two generations in Burnaby in 1997, and a substantial increase in population density occurred between the first and second generations. Pupal parasitism reached high levels (>40% parasitism) during the first generation in this population, but larval parasitism occurred at a very low level. Dispersal of large numbers of second-generation larvae on silken threads, and subsequent pupation on parked vehicles on residential streets, cause much of the pest impact of this "nuisance" insect. Attack by pupal parasitoids in the first generation probably reduces the pest impact of these second-generation larvae.

**Key words:** *Bucculatrix ainsliella*, British Columbia, life history, Lyonetiidae, oak skeletonizer, parasitoids, pest management, red oak, *Quercus rubra*

## INTRODUCTION

The oak skeletonizer, *Bucculatrix ainsliella* Murtfeldt (Lepidoptera: Lyonetiidae), is a common pest of oak and chestnut trees in urban areas of eastern North America (Murtfeldt 1905; Gibbons and Butcher 1961; Johnson and Lyon 1991; Dreistadt 1994). This urban tree pest was first recorded in the Vancouver area in 1980, presumably after an accidental introduction (R. Duncan, PFC, Canadian Forest Service, personal communication; Morris and Wood 1980). At present, there is no information available regarding the life history or parasitism of *B. ainsliella* in southwestern British Columbia. Here, we report the results of a sampling program for *B. ainsliella* conducted during the summer of 1997 in an area of infested red oak trees (*Quercus rubra* L.) in Burnaby, BC.

Like many Microlepidoptera, *B. ainsliella* undergo a change of feeding habit during larval development (Gaston *et al*. 1991). During early larval development, *Bucculatrix* spp. feed as leafminers within the leaf tissue of the host. Later in development, the larvae emerge from the leafmines and feed externally on leaves (Hering 1951). It is during this second larval stage that physical damage to urban shade trees can occur, although heavy

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defoliation is rare (Johnson and Lyon 1991, Dreistadt 1994). After emerging from the leafmine, externally-feeding larvae undergo two molts that occur in silken "tents" spun on the undersurface of the leaf (Gibbons and Butcher 1961). Final-instar larvae pupate in characteristically ribbed cocoons that are spun of silk and usually occur on leaves during summer generations (Murtfeldt 1905; Gibbons and Butcher 1961; Johnson and Lyon 1991; Dreistadt 1994). Larvae of the final generation of the year spin off trees on silken threads ("ballooning" behaviour), build cocoons, and pupate on virtually any sheltered substrate they encounter, where they overwinter in the pupal stage. Larval ballooning behaviour from heavily infested trees, and subsequent pupation in crevices on parked cars, are the causes of most complaints from residents that live near infested oak trees along city streets.

For the past several years, a population of *B. ainsliella* has infested a group of red oaks planted as shade trees in a residential area of Burnaby. The infestation has resulted in frequent complaints by residents, particularily in years of high population density. This paper reports the results of a sampling program conducted in the summer of 1997 in which we recorded the seasonal occurrence of life-history stages, and parasitism of larvae and pupae, in this Burnaby population of *B. ainsliella*.

## MATERIALS AND METHODS

*Study site.* The study site was located along six blocks of Ingleton Ave. and five blocks of Cambridge St. near the intersection of these two streets in North Burnaby, BC. Approximately 100 red oak trees are planted along the two streets as shade trees. The trees are between 15 and 20 years old and range between 3 and 12m in height. The site was divided into five sampling sections containing approximately 20 trees each.

*Leaf sampling.* One tree was randomly selected from each of the five sections, without replacement, on each sampling week for removal of a leaf sample. Leaf samples were taken weekly over a 19 week period from 23 May [Week 1] to 25 September, 1997 [Week 19] except for 18 September [Week 18] when no sample was taken. For each sample, the terminal ends of 20 branches, each with four to five leaves attached, were removed from the lower half of the crown with pole pruners. Branches were bagged separately, labelled, and returned to the laboratory. The leaves were examined under a dissecting microscope and the number of *B. ainsliella* eggs, early-stage larvae [leafminers], late-stage larvae [external feeders] and pupae were counted and recorded for each branch.

*Larval and pupal parasitism.* Leafmines and molting tents were dissected to determine whether larval ectoparasites were present, and the number of parasitized larvae per branch sample was recorded. Percent larval parasitism was calculated for each branch by dividing the number of parasitized larvae by the total number of larvae and pupae on the branch and multiplying by 100. Pupae from the same generation are included in the estimate of parasitism since they are individuals that escaped larval parasitism and progressed to the next life-history stage. All pupae collected from each sample tree in sampling weeks 6 through 13 were held at ambient temperature in the laboratory and the number of emerging adult *B. ainsliella*, the number of emerging adult parasitoids, and the number of dead pupae were recorded. Percent pupal parasitism per sample tree was calculated by dividing the number of pupae from which parasitoids emerged by the total number of pupae per tree and multiplying by 100. Adult parasitoids reared from pupae were identified to family or superfamily.

*Data analysis.* Means and standard errors of the numbers of *B. ainsliella* eggs, early larvae, late larvae and pupae, and percent larval parasitism per branch were calculated

across all branches taken in all sections of the site on each sample date ($n=100$ for branches per sample date). Means and standard errors of percent pupal parasitism were calculated per sample tree for weeks 6 through 13 ($n=5$ for sample trees per sample date). Statistics were calculated using Systat (Wilkinson *et al.* 1992).

## RESULTS

*Bucculatrix ainsliella* completes two generations per year in Burnaby. The phenology of eggs, early larvae, late larvae and pupae through the season is given in Figure 1. A substantial increase in population size occurs in the second generation of the year. Larval parasitism by unidentified hymenopterous ectoparasitoids occurred at a low level (Figure 2). The highest level of larval parasitism by ectoparasitoids was recorded during the first generation in week 11 when mean larval parasitism per branch was 9.4%. Pupal parasitism of first-generation *B. ainsliella* occurred at a much higher level than larval parasitism (Figure 3). The highest level of pupal parasitism during the first generation was recorded in week 10 when mean pupal parasitism per sample tree was 44.4%. Adult parasitoids reared from *B. ainsliella* pupae were either from the family Ichnuemonidae or the superfamily Chalcidoidea (Goulet and Huber 1993). The Ichnuemonidae made up 63% of the recovered parasitoids and the Chalcidoidea made up the remaining 37%.

## DISCUSSSION

The increased size of the *B. ainsliella* population in the second generation is responsible for much of the pest impact of this insect. In late summer, ballooning behaviour by large numbers of larvae, and subsequent pupation on parked vehicles, is more disturbing to residents than any damage sustained by the trees. The results of this study show that substantial mortality occurs in the first generation due to pupal parasitism. This indicates the potential for the Burnaby population to be reduced by natural parasitism to a level tolerable to residents. However, second generation populations in 1997 still increased substantially after mortality by pupal parasitoids. Parasitism by larval ectoparasitoids, in contrast, does not cause substantial mortality. No attempt was made, in this study, to quantify larval endoparasitism, although endoparasitoids may have made an additional contribution to larval mortality. Mass-rearing of either larval or pupal parasitoids of *B. ainsliella* for inundative releases is probably impractical because of the expense of raising the plant [oak trees] and host material required for rearing. However, it may be possible to manipulate natural parasitoid populations in order to increase the level of control, for example by using semiochemicals.

Because the population level of late-stage larvae in the second generation is so high, one possible management approach would be to release generalist predators in an attempt to reduce the population before ballooning behaviour commences. On several occasions during the second generation, larvae of green lacewings (Chrysopidae) were observed on leaves in association with late-stage larvae, and on one occasion a lacewing larva was observed feeding on a *B. ainsliella* larva. Because green lacewings are available from commercial insectaries, it is possible that inundative releases of lacewings could reduce the population of second-generation larvae. Spray applications of insecticidal soap or microbial insecticides like *Bacillus thuriengensis* might also be effective in reducing the second-generation larval population. Because early-stage leafmining larvae are sheltered within the leaf tissue, any releases of biological controls like lacewings, or spray

applications of soap or *B. thuriengensis*, should be timed to target externally-feeding late-stage larvae.
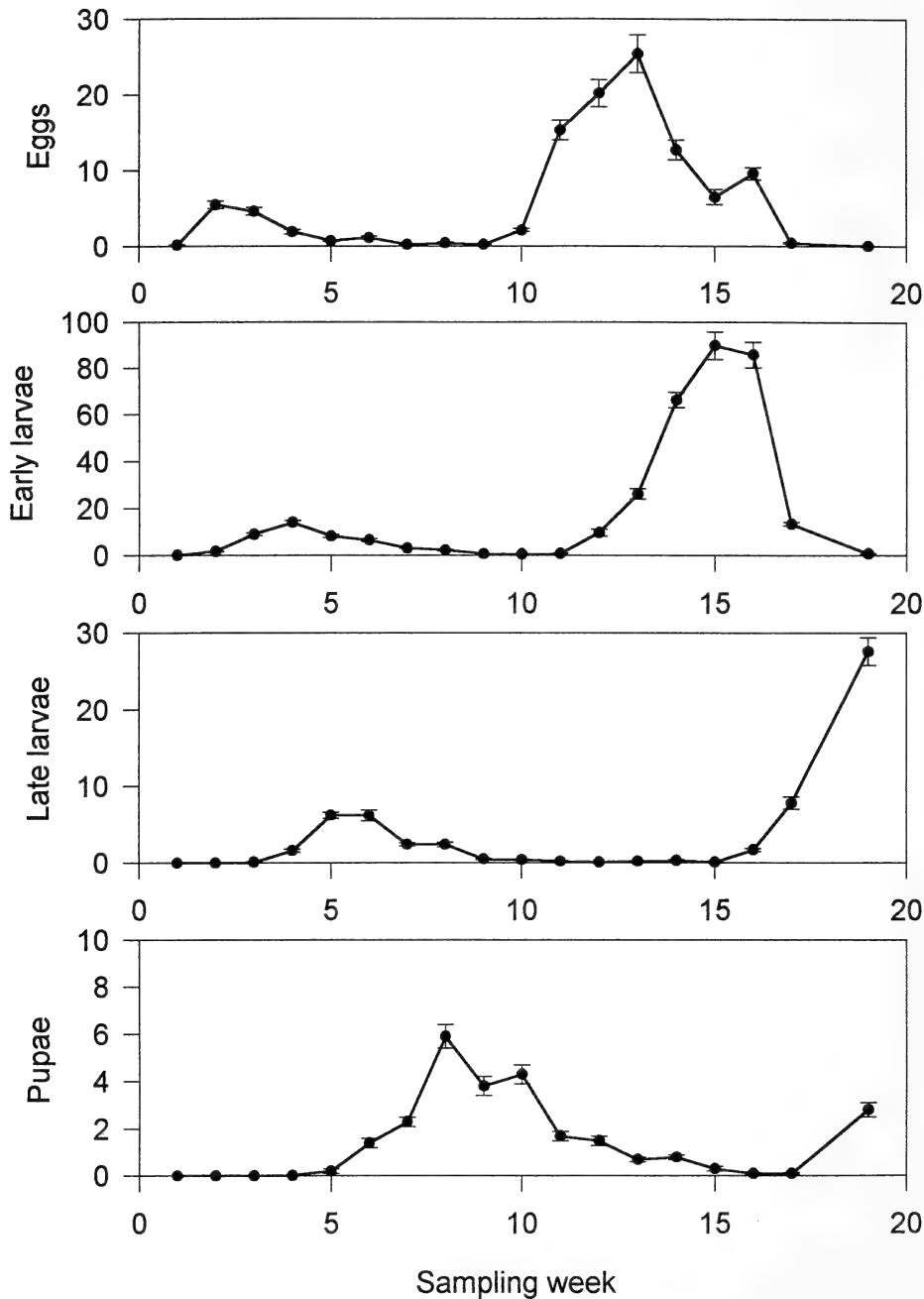


**Figure 1.** Seasonal abundance of *B. ainsliella* eggs, early larvae, late larvae and pupae in consecutive sampling weeks in North Burnaby in 1997. Closed circles and error bars show means per branch sample ± SE.

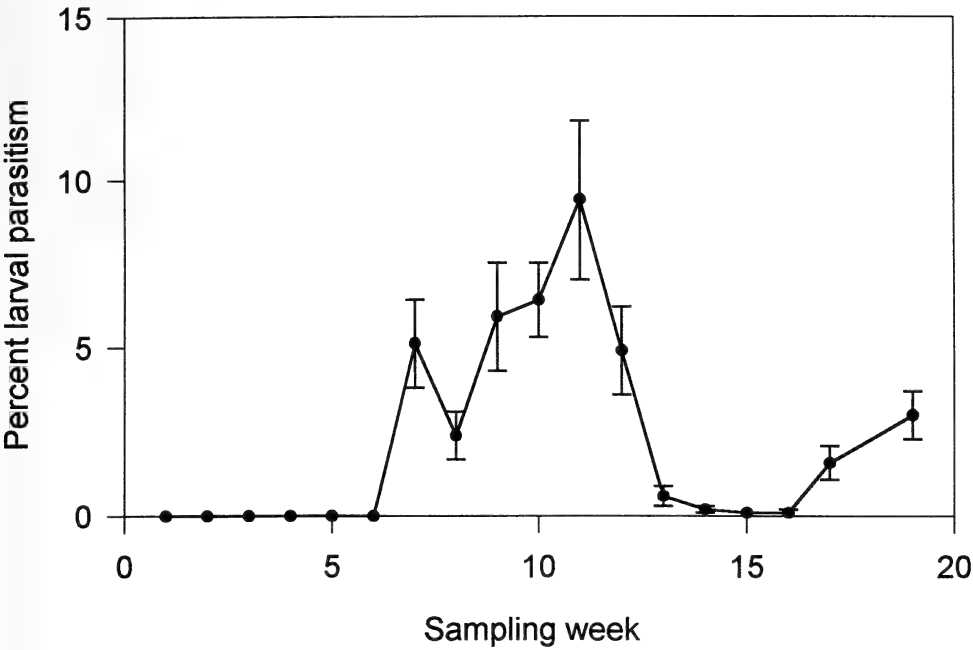**Figure 2.** Percent parasitism of *B. ainsliella* by larval ectoparasitoids in consecutive sample weeks in North Burnaby in 1997. Closed circles and error bars show means per branch sample ± SE.
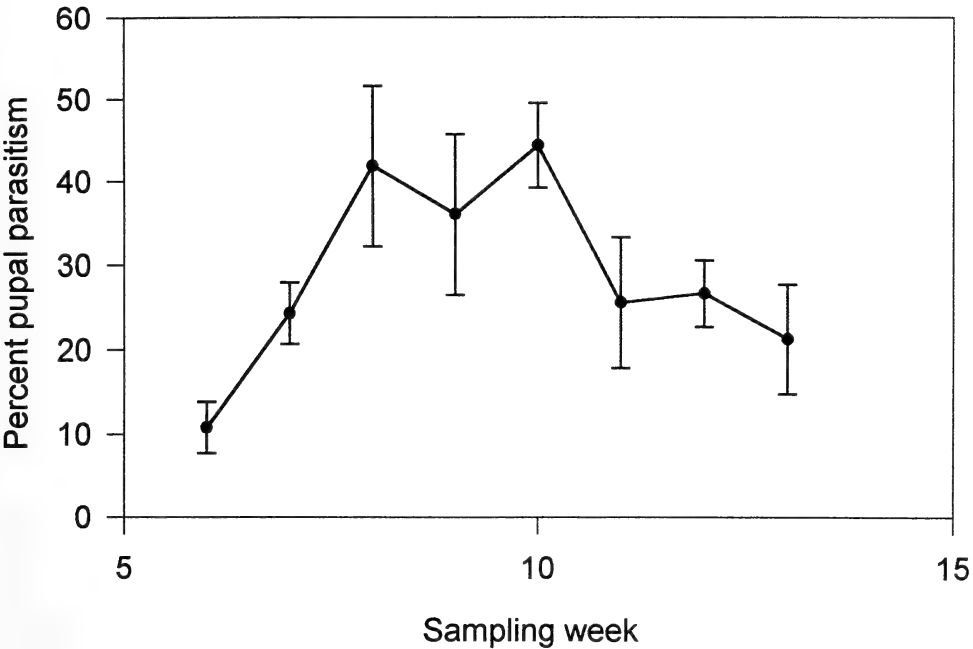


**Figure 3.** Percent pupal parasitism of *B. ainsliella* in consecutive sample weeks in North Burnaby in 1997. Closed circles and error bars show means per sample tree ± SE.

The pest status of this insect depends directly on the location and density of a given population. When a high density population of *B. ainsliella* occurs in an urban area, this insect can create a nuisance for residents. This study has shown that natural parasitism of *B. ainsliella* pupae may contribute to reducing the impact of this pest. Further assessment of the role of parasitoids in regulating *B. ainsliella* populations would require longer-term monitoring of the host and parasitioid populations.

## ACKNOWLEDGEMENTS

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# Lack of evidence for pheromone-mediated secondary attraction in the fir engraver, *Scolytus ventralis* (Coleoptera: Scolytidae)

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## ABSTRACT

To test the hypothesis that host selection and mass attack by the fir engraver, *Scolytus ventralis* LeConte, is mediated in part by pheromones, an exhaustive series of experiments was conducted. Gas chromatographic (GC) analysis and GC-electroantennographic detection analysis was performed on Porapak Q-captured volatiles from virgin and mated beetles of both sexes, logs of grand fir, *Abies grandis* (Dougl.) Lindl., with males, females or both sexes boring in the bark, and trees undergoing attack in the field, and on extracts of abdominal tips from beetles topically-treated with methoprene, a juvenile hormone analogue, or beetles boring in methoprene-treated bark of grand fir. None of these analyses disclosed any sex-specific compounds or compounds that changed markedly in concentration following treatment. Extracts of the females' terminal abdominal glands with associated vaginal palpi contained *exo*-brevicomin, a common aggregation pheromone in the genera *Dendroctonus* and *Dryocoetes*, but laboratory and field experiments showed it to have no apparent role in long-range orientation. Extensive visual and videotaped observations revealed that females walking on grand fir bark displayed apparent "calling" and "marking" behavior, and during courtship males rubbed the females' abdominal declivity with their frons, placing their antennae in juxtaposition to the females' vaginal palpi. These results are consistent with the alternative hypothesis that host selection and mass attack by *S. ventralis* are mediated solely by primary attractants from the host tree, but they do not rule out the possibility of short-range pheromone-mediated behavior.

**Key words**: *Scolytus ventralis,* Coleoptera, Scolytidae, chemical ecology, pheromones, host selection

## INTRODUCTION

For over four decades, entomologists have investigated (and debated) the process by which the fir engraver, *Scolytus ventralis* LeConte, locates and colonizes its host trees, primarily grand fir, *Abies grandis* (Dougl.) Lindl., and white fir, *A. concolor* (Gord. & Glend.) Lindl. (Struble 1957; Vité and Pitman 1967; Ashraf and Berryman 1969; Berryman and Ashraf 1970; Ferrell 1969, 1971). We have recently produced conclusive

evidence for primary (host) attraction of *S. ventralis*, and demonstrated that attraction to traps in the field can be induced by a blend of 13 antennally-active volatiles from the bark of grand fir (Macías-Sámano *et al.* 1998). We argue that mass-attack by this species can be achieved solely through response to host volatiles. Part of this argument rests on an exhaustive series of experiments that produced no evidence for long-range secondary (pheromone-mediated) attraction in this species. Herein we present a summary of these experiments, and report some behavioral observations indicating the occurrence of close-range olfactory communication and courtship behavior.

## AERATIONS OF BEETLES IN THE LABORATORY

Volatiles produced by groups of male, female or mixed sex *S. ventralis* were collected on Porapak Q following a standard aeration procedure (Macías-Sámano *et al.* 1998). Unless otherwise noted, the aerations were performed at 20 °C with a 12:12 h L:D regime; prior to aerations all insects were kept for up to 4 days at ca 4 °C in glass jars with moistened paper. Fresh grand fir logs were used as host material. In order to reveal possible variations in the volatile production by insects alone and/or insects plus host material, aerations were performed in the following sequence over 36 months.

1.  Separate aerations of 104 unfed virgin females and 72 unfed virgin males in glass tubes (30 cm long and 3 mm diam.) for 312 h.

2.  Aeration of 17 unfed virgin females and males in the same glass tube for 384 h.

3.  Separate aerations for 168 h under darkness at ca 25 °C of bolts placed inside metal drums (70 cm long and 45 cm diam.), and attacked by 130 virgin females or 130 virgin male beetles introduced into preformed entrance holes.

4.  Aeration of 130 females and 130 males boring together into a bolt under the above conditions for 120 h. Females were introduced into the bolts three days before the males.

5.  Aerations of 154 virgin females or 236 virgin males individually boring for 96 h into grand fir logs inside glass aeration chambers (Macías-Sámano *et al.* 1998). All beetles had emerged the same day and were not cold stored. One uninfested control log (20 cm diam.) was aerated under the same conditions.

6.  Aerations of 312 females and 175 males boring in grand fir bolts in separate glass chambers for 216 h, with Porapak Q volatile capture devices replaced with fresh devices after 60 h.

7.  Above aerations repeated with 303 females and 120 males.

8.  Aeration of 184 females and 106 males boring together (97 of each sex established pairs in galleries) in bolts inside a glass chamber for 192 h.

9.  Aerations of males and females added daily to separate glass chambers containing grand fir bolts. First day, 84 females and 84 males. On days 2-4, 83 and 32, 163 and 79, and 38 and 13 males and females, respectively, were added. Aerations were conducted inside glass chambers for 288 h. All insects had emerged on the same day and were not cold-stored.

10. Aerations of 50 females and 50 males inside the same glass tube (as above) for 48 h. All insects had emerged the same day and were not cold-stored.

11.    Aerations in glass chambers of beetles separated by a mesh from infested and
        uninfested grand fir bolts.   First aeration: 50 females and 50 males in separate
        chambers with a screen-enclosed fresh uninfested grand fir bolt for 192 h.   Second
        aeration: 25 males with logs infested by 25 females for 192 h.   Third aeration: 26
        females and 26 males in separate chambers boring into fresh grand fir logs (insects
        and bolts screen-enclosed), to which were added 26 females and 21 males,
        respectively, for 168 h.   In this last aeration, the enclosed insects were placed on the
        logs two days before introduction of the other insects.   Porapak Q volatile capture
        traps were replaced after 48 and 120 h.

Differential diagnosis (Vité and Renwick 1970) was carried out on male and female
volatile extracts obtained in the different aerations to search for sex-specific compounds.
Gas chromatographic (GC) analyses employed Hewlett Packard 5830A, 5880A, and
5890A instruments equipped with capillary inlet systems and FID.   Fused silica columns
(30 m x 0.25 or 0.32 mm ID) coated with SP-1000 (Supelco, Bellefonte, Pennsylvania) or
DB-1 (J &W Scientific Inc., Folsom, California) were used.     Coupled GC-mass
spectrometry (MS) employed a DB-23 column and a Varian Saturn ion trap.   Helium was
the carrier gas for GC and GC-MS.     Differential diagnosis showed neither insect-
produced nor sex-specific compounds.

These results were supported by coupled GC-electroantennographic detection (EAD)
analyses (Gries 1995) with male and female antennae, of the captured volatiles from
aeration 9.   A Hewlett Packard 5890 A instrument equipped with a DB-23-coated fused
silica column (30 m x 0.32 mm ID; J & W Scientific) was used.   Responses from excised
antennae were amplified by utilizing a custom-built amplifier with a passive low pass
filter and cutoff frequency of 10 kHz.     Compound identities were confirmed by
comparison of their retention times and mass spectra with those of authentic samples.
GC-EAD analyses also revealed no candidate pheromones.   The only clear trend was to
observe high quantities of antennally-active host volatiles from those aerations in which
the insects were actively boring into bolts or branches of grand fir.

## AERATIONS OF TREES IN THE FIELD

Field aerations were conducted in a mature *A. grandis / Acer rubrum* L. forest with
well represented Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco (Steel and Gier-Hayes
1992), located 10 km North of Coeur d'Alene Idaho.   Adapting the methodology of
Browne *et al.* (1979), 1 m long sections of the bole of six standing grand fir trees (mean
diam. at 1.3 m = 83.2 cm) under attack by *S. ventralis* were wrapped in a clear plastic
sheet open at the top with the sealed bottom exiting into a Porapak Q volatile trap.   Air
was drawn at 1.5 L per min through the trap under vacuum from a portable pump
connected to a power generator.   Two unattacked trees ca. 3 m from the trees under attack
were also wrapped and sampled as controls.   The aerations lasted 49 ± 1.5 h.

GC analyses (conditions as above) of the captured volatiles showed no conspicuous
differences between infested and uninfested trees, reinforcing the results of laboratory
aerations.   Comparative GC-EAD analyses of volatiles from one infested-tree and one
control tree aeration showed no significant differences in antennal responses.

## JUVENILE HORMONE TREATMENTS

Juvenile hormone (JH) and JH analogues are known to promote pheromone production in the following scolytid species: *Ips paraconfusus* (Lanier) (Borden *et al.* 1969; Hughes and Renwick 1977a; Chen *et al.* 1988), *Trypodendron lineatum* (Olivier) (Fockler and Borden 1973), *Pityogenes chalcographus* L. (Francke *et al.* 1977), *Dendroctonus brevicomis* (Hughes and Renwick 1977b), *Pityokteines* spp. (Harring 1978), *Scolytus scolytus* F. (Blight *et al. 1978),* and *D. ponderosae* Hopkins (Conn 1981). These results led us to test the hypothesis that if *S. ventralis* produces an aggregation pheromone, treatment of beetles with JH should disclose evidence of that pheromone.

Accordingly, female and male *S.ventralis* that had emerged from logs within the past 24 h, or were excised from the bark after feeding in fresh grand fir logs for 48 h, were topically treated with 1 µg or 10 µg of methoprene (isopropyl-11-methoxy-2, 6, 11-trimethyl-2, 4-dodecadienoate), a juvenile hormone analogue, in 1 µl of pentane (Fockler and Borden 1973; Pierce *et al.* 1986). Newly-emerged control beetles were treated only with 1 µl of pentane. Each treatment was replicated with 20 beetles. Treated beetles were individually placed in gelatin capsules attached to a suitable grand fir log under room conditions. The insects were excised from the bark after 24 h, sorted by treatment, and their entire bodies were immediately extracted in pentane. The extracts were filtered through glass wool and analyzed by GC as above. A second 20-replicate experiment was designed following a modification of the technique used by Chen *et al.* (1988), with 1 µg of methoprene or pentane applied just to the circular area of the log circumscribed by the perimeter of the gelatin capsule holding the beetle in contact with the bark. The beetles would contact or ingest the methoprene while boring into the log. Only unfed insects were employed and they were placed on the log 2 h after the methoprene was applied to the bark surface. Pentane treatments were used as controls. Extracts were obtained and analyzed as above.

In no instance did GC analyses of extracts from treated and control insects reveal any compounds that changed in amount as a result of JH treatment, nor were there any evident sex-specific compounds.

## GLAND EXTRACTS

Because the terminal abdominal accessory glands with their associated vaginal palpi have been implicated in the production of α-multistrain by *Scolytus multistriatus* Marsham (Gore *et al.* 1977), we examined female *S. ventralis* for similar evidence of pheromone production. Abdominal tips of 289 female beetles that had fed in grand fir bark for 5 days were obtained by dissection. The abdominal tip was exposed by a gentle squeeze of the insect's body, removed from the body with microscissors, and immediately crushed in pentane. The presence of the accessory gland with vaginal palpi in 20 excised tips was confirmed by microscopic examination.

GC-EAD analyses using male antennae followed by GC-MS analyses revealed the presence of *exo*-brevicomin, *exo*-7-ethyl-5-methyl-6, 8-dioxabicyclo[3.2.1]octane, in trace amounts in the female abdominal tip extracts. *Exo*-brevicomin is an important pheromone in the genera *Dendroctonus* and *Dryocoetes* (Borden 1985; Camacho *et al.* 1993), and has not previously been found in *Scolytus* spp.

Laboratory bioassays and field trapping experiments (Macías-Sámano *et al.* 1998) revealed no behavioral effect of *exo*-brevicomin on *S. ventralis*. However, there could be a link between the fact that *exo*-brevicomin is present in the female abdominal tip and the

"marking" and "calling" behavior revealed by videotape analyses (see below). It is possible that *exo*-brevicomin serves as a short range cue for male *S. ventralis* to detect a site with females in the vicinity, acts as a courtship inducer, or an epideictic (spacing) pheromone (Prokopy 1981) that accounts in part for the non-random distribution of *S. ventralis* attack (Berryman 1968), or serves as an allelochemic that suppresses attack by potential competitors.

## VISUAL AND VIDEOTAPED OBSERVATIONS

Laboratory observations were made on at least 40 beetles placed on cut bolts of grand fir and allowed to attack freely in the laboratory. Similar observations were made in the field from at least 80 individuals. Beetles that took flight during laboratory observations were replaced. When this behavior prevailed, the log was replaced because it was considered unsuitable. When a particular behavior was observed, the sex or sexes involved were determined.

The behavior of 20 beetle pairs was documented by micro-and macro-videotaping at 22 °C and ambient light during 20 h of taping. Twenty beetles of each sex were allowed to run freely and bore into fresh bolts (50 cm long and 15 cm diam) that were vertically (10 beetle pairs) or horizontally (10 beetle pairs) set on a laboratory bench (scenario 1). Ten more beetles of each sex were placed on one log (5 pairs) and on 10 green branches with needles (5 pairs), in which females (20 in the log and 20 in the branches) had been boring for 48 h (scenario 2).

We used a Panasonic solid state camera WV-CD 110, fitted to either a Karl Zeiss surgical microscope or to a 50 mm (1:2.8) SMC Pentax-A macro lens, coupled to a 50 mm Vivitar 2x macro focusing teleconverter macro, depending on the degree of magnification needed. The camera was connected to a Panasonic GX4, Multifunctional Video Cassette Recorder AG-195, and the image was monitored with a Panasonic Color Video Monitor CT-1330-MC. Illumination was provided by a cold-light source (Schott KL 1500).

Observations were also made in the field. On 2 July, 1996, five uninfested 1.3 m-long logs of grand fir were set up vertically in an open area of a grand fir forest near Coeur d'Alene, Idaho. When the first *S. ventralis* started to arrive at the logs, visual observations of boring, courtship, and mating activities were made from 0900 h to 1800 h for three consecutive days.

*Scenario 1.* Most of the beetles were very mobile and fast walking. Often when two individuals (sex not determined) approached each other a very brief "wrestling" occurred by rubbing their frons. After about 10 min on the log, many beetles appeared to select a spot where they would bore into the bark. At this time several females performed one of two conspicuous behaviors. The majority were extruding the tip of the abdomen and rubbing it on the bark as they walked in a zigzag fashion (Figure 1) that suggests a "marking" behavior as occurs in some moths (Swier *et al.* 1976; Colwell *et al.* 1978; Szocs and Toth 1979; Teal *et al.* 1981; West and Bowers 1994). Each marking bout lasted about 30 s, and was repeated several times for up to 5 min. The second pattern, displayed by only two females, may have been a variation of the previous behavior. These females extruded and raised the very swollen tip of their abdomens, and walked in a zigzag fashion, emulating moth "calling" behavior (Figure 1) (Turgeon and McNeil 1982; Alford and Diehl 1985; West and Bowers 1994). Such activity lasted < 30 s, and was repeated several times in 5 min. Both "marking" and "calling" were not disturbed by nearby beetles of either sex, and "marking" occurred whether the logs were placed

horizontally or vertically. The "marking" behavior was seen again when two females were exposed to 0.25 mg of bark oil in an olfactometer (Macías-Sámano *et al.* 1998). To our knowledge these two behavioral patterns have not been reported for any other bark beetle.



"Calling" Behaviour
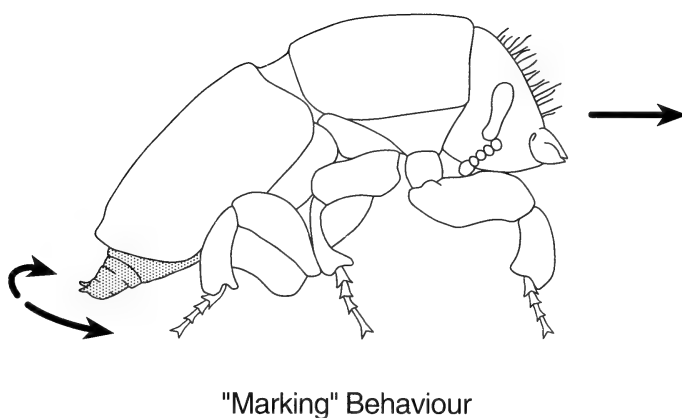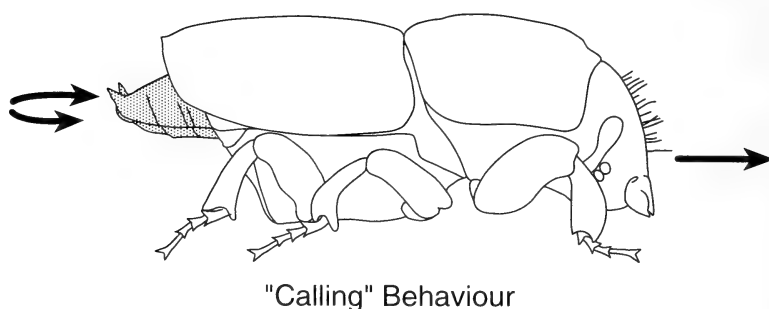


"Marking" Behaviour

**Figure 1**. Apparent "marking" and "calling" behavior observed in videotape analysis of female *S. ventralis* with conspecifics on the bark of grand fir logs. Arrows indicate direction of locomotion and abdominal movements.

*Scenario* 2. All 10 females that had bored for 48 h into the bolt were observed in courtship and later in mating, as were the 10 females boring into branches, mainly at the twig crotches. The behavior was very similar to that found for *S. multistriatus* (Svihra and Clark, 1980), and confirmed the observations by Struble (1957) and Ashraf and Berryman (1969) for *S. ventralis*. All 40 couples mated outside the gallery, despite its length and the presence of a "nuptial" chamber, which is apparently used more as a turning area inside the gallery than for mating.

Each female waited within the gallery entrance facing inward. Courtship started when a male began to nod his head rhythmically against the abdominal declivity of the

female, possibly also stridulating. This action lasted up to 1 min and placed the male's antennae very close to or in contact with the vaginal palpi. The male then turned around and without inverting himself, as in some other scolytids (Francke-Grosmann 1951; Reid 1958), copulated with the apparently passive female who remained at the entrance. Defecation by females occurred frequently during courtship. Sometimes during courtship the males extruded their aedeagus once or twice, before initiating copulation.

In some cases a female arrived at an entrance occupied by another female, and apparently induced the resident female to leave, whereupon the intruder replaced her. On several occasions when a female was deep within a gallery, a male entered the gallery, and apparently enticed the female to the entrance by means of vigorous "nodding" on her abdomen, as also reported for *S. mali* (Doganlar and Schopf 1984). This episode required 2-4 min and was followed immediately by copulation.

All females copulated at least twice with the same male. In periods of observation up to 3 h long, no male remained with a female after the second copulation. Males copulated on average with three different females. Copulation lasted an average of $45 \pm 3.5$ s ($\bar{x} \pm SE$).

*Field observations.* Observations in the field confirmed the laboratory observations on courtship and mating behavior including the promiscuous behavior of both males and females. Two males were heard stridulating while in courtship. Rivalry displays between insects of the same sex were more pronounced, and females stole entrance holes more often. The speed at which 10 beetles walked up and down the logs was timed at 0.63 m per min. This walking speed, and the fact that the beetles never walked straight, suggest that *S. ventralis* could easily visit several trees a day, and assess their suitability as hosts as well as their occupancy by potential mates.

# ACKNOWLEDGEMENTS

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*COVER*: Male *Gnaphosa snohomish* Platnick & Shadab (Araneae, Gnaphosidae). From Burnaby, British Columbia (collected by Jim Troubridge). Drawn by Robb Bennett. Body is approximately 11 mm in length.

The Holarctic genus *Gnaphosa* contains around 120 species of nocturnally active, ground dwelling hunting spiders. Twelve species are known in Canada with six of these occurring in British Columbia. Found in a very wide array of habitats from sea level to mountain tops and from the tropics to the arctic, specimens of *Gnaphosa* are often very abundant and may turn up in large numbers in pitfall traps. In the summer of 1998, a very strong, local population of *Gnaphosa snohomish* (previously known only from two specimens from Chase Lake, Snohomish County, Washington and a questionable BC record from Haney (Maple Ridge) was discovered in an abandoned cranberry bog in Burnaby, BC. The site has since been cleared and reactivated as a commercial bog and the current status of this population (and the species) is unknown. Given the large number of entomologists that call or have called the lower Fraser Valley home, it is reasonable to assume that the insect and spider fauna of the area should be reasonably well known. This discovery suggests that 1) either *G. snohomish* exists in localized, very restricted populations or 2) our knowledge of the natural history of the most heavily populated region of our province is less than we think. Text by Robb Bennett.

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# A new and unusual host plant record for the rare moth *Lasionycta wyatti* (Lepidoptera: Noctuidae)

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## ABSTRACT

Moths reared from larvae collected from sand around the bases of silver burweed (*Ambrosia chamissonis* [Less.] Greene) at Tsawwassen, BC were identified as the rare noctuid *Lasionycta wyatti* (Barnes & Benjamin). Thiarubrines, toxic secondary compounds produced by *A. chamissonis*, are well tolerated by these larvae. This constitutes a new hostplant record for the species.

**Keywords:** *Lasionycta, Ambrosia*, thiarubrines, insect-plant chemical interaction.

## DISCUSSION

*Lasionycta wyatti* (Barnes & Benjamin)(Lepidoptera: Noctuidae) has a reported distribution along the west coast of North America from central British Columbia to northern Washington (J. Troubridge, pers. comm.). Little is known of the natural history of this species, but Crumb (1956), who "…collected many larvae on coastal sand dunes in Washington and Oregon," listed its host plants as beach buckwheat (*Polygonum paronchia* Cham. & Schlecht.), beach verbena (*Abronia latifolia* Eschsch.), seaside tansy (*Tanacetum douglasii* D.C.), "…and a slender grass which roots at the nodes."

In 1995, larvae of an unidentified species of noctuid were collected from the sand surrounding silver burweeds (*Ambrosia chamissonis* [Less.] Greene, Asteraceae) at Centennial Beach in Boundary Bay Regional Park, Tsawwassen, BC. The following year, additional larvae were collected from the same location and reared on artificial medium to pupation. The resulting adult moths were later positively identified as *L. wyatti* (J. Troubridge and D. Bright, pers. comm.). Voucher specimens are archived at the Canadian National Collection (Ottawa) and the Spencer Entomological Museum (University of British Columbia, Vancouver).

To locate larvae, scrupulous digging was done around the bases of *A. chamissonis* plants. Sand to a depth of 5-10 cm was brushed aside using a hand-held trowel, a shovel, or simply by hand. In late April to early May when larvae were collected in 1996 and 1997, they were in the second or third instar. The distribution of larvae found at the bases of plants was uneven. Some plants lacked larvae, while at others, from 2-20 larvae were found. Larvae were almost always found around the bases of *A. chamissonis* plants that showed subterranean feeding damage. Most of the larvae were collected from the top 5-10 cm of sand surrounding the succulent subterranean stems, but none were found at 20-30 cm below the surface where the woody roots begin. No larvae were found in the sand surrounding other species of randomly selected plants in close proximity to *A. chamissonis*.

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Silver burweed (*A. chamissonis*) is chemically characterized by the production of a diverse array of polyynes, known as thiarubrines, in the roots, stems and leaves (Ellis 1993) that are toxic to bacteria, fungi and certain insects (Towers *et al.* 1985; Ellis *et al.* 1995; Guillet *et al.* 1997). Liquid chromatographic analyses of field-collected larvae and their frass revealed relatively high levels of thiarubrines, with patterns remarkably similar to that of *A. chamissonis* stem extracts (Dojillo-Mooney *et al.*, 1999). These results, together with the lack of detectable levels of thiarubrines in the sand surrounding *A. chamissonis* plants provide unambiguous evidence that this population of *L. wyatti* larvae are using *A. chamissonis* as a host plant. Furthermore, laboratory bioassays established that thiarubrines from *A. chamissonis* are well tolerated by larvae whereas they impair the growth of the generalist feeder *Spodoptera litura* Fab. (Noctuidae) and cause significant mortality in the non-adapted specialist *Manduca sexta* (L.)(Sphingidae)(Dojillo-Mooney *et al.* 1999).

It is interesting to note that *L. wyatti* larvae are reported to feed on *Tanacetum douglasii*, as *Tanacetum* species are known to produce toxic acetylenes and thiophenes in their roots. The latter compounds are breakdown products of thiarubrines; thus *Tanacetum* and *Ambrosia* are related both taxonomically and with respect to their secondary chemistry. On the other hand, *Polygonum* (Polygonaceae) and *Abronia* (Nyctaginaceae) are relatively unrelated and do not produce characteristic secondary compounds that would explain their utilization as hostplants by *L. wyatti*.

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# Preliminary study of fungus gnats (Diptera: Mycetophilidae) from the Carmanah Valley, Vancouver Island British Columbia[1]

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## ABSTRACT

The types of *Macrocera uniqua* Garrett, *Syntemna vernalis* Sherman, *Dziedzickia columbiana* Sherman, *Docosia setosa* Garrett and *Tetragoneura marceda* Sherman have been examined to re-evaluate their identities.

**Key words:** Mycetophilidae, Garrett, Sherman, *Fenderomyia*, *Dziedzickia*, *Syntemna*, *Docosia*, *Megophtalmidia*, *Tetragoneura*

## INTRODUCTION

The following study of fungus gnats results from a survey of the old-growth rain forest in the Upper Carmanah Valley by Dr. N.N. Winchester. This undisturbed woodland lies on the west coast of Vancouver Island, British Columbia. Several synonymies and new combinations are treated and one homonym is re-named.

## SYSTEMATICS

Macrocerini
*Fenderomyia* Shaw,1948.

In a recent paper, Matile (1997) examined a single specimen of *F. smithi* Shaw. As a result he validated the genus which Coher (1963) had placed as a junior synonym of *Macrocera* Meigen. A series of flies from Vancouver Island verify both Shaw's (1948) and Matile's (1997) proposal. Matile pointed out the value and validity of pleural characteristics in combination with other characteristics noted by Shaw.

The male holotype of *Fenderomyia smithi* is mounted on a slide in the insect collection of the University of Massachusetts, Amherst.

*Fenderomyia uniqua* (Garrett), 1925 **n. comb.**
*Macrocera uniqua* Garrett,1925a:8.
*Fenderomyia smithi* Shaw, 1948:94 **syn. n.**
**Records**: CANADA British Columbia , Vancouver Island, Upper Carmanah Valley, 21 June - 3 July,1991, 8 males, 57 females; 4 - 15 July,1991, 3 females; 12- 27 August,1991, 4 males. Malaise trap, N. Winchester.

The male holotype from eastern British Columbia is more robust than Vancouver Island specimens which are less pigmented. Differences of the male terminalia between the two are in size and robustness only. The abdomen of the female type of *M. uniqua* is missing.

Sciophilini
*Syntemna* Winnertz,1863.

Sherman [1921] described several species of *Dziedzickia* which were transferred to *Syntemna* by Vockeroth (1980). My examination of the holotype of *Dziedzickia*

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*columbiana* Sherman confirms it as a junior synonym of *Syntemna hungarica* (Lundström). In addition the following synonymy is noted.

*Syntemna vernalis* Sherman, [1921].

*Dziedzickia vernalis* Sherman, [1921]:16.

*Syntemna vernalis* (Sherman). Vockeroth,1980:543.

*Syntemna johannseni* (Sherman), [1921]:17, **syn. n.**

The female terminalia of the types of *Dziedzickia vernalis* Sherman, [1921] and *D. johannseni* Sherman, [1921] are identical with those of a long series of females taken with males of *S. vernalis*.

**Records:** CANADA: British Columbia , Vancouver Island, Upper Carmanah Valley, 21 June - 3 July,1991, 16 males, 5 females; 4 - 15 July,1991, 6 males , 2 females; 31 July - 11 August,1991, 4 males, 2 females; 12 - 27 August,1991, 11 males , 2 females; 28 August - 9 September,1991, 5 males, 7 females. Malaise trap, N. Winchester.

Tetragoneurini (Leiini)

*Docosia* Winnertz,1863.

*Docosia columbiana* Coher, **nom. nov.**

*Docosia setosa* Garrett,1925b:12. Preoccupied by *Docosia setosa* Landrock,1916:63.

*Docosia columbiana* Coher, **nom. nov.** for *D. setosa* Garrett,1925b, nec *D. setosa* Landrock,1916.

I have examined the male holotype. The terminalia has "ventrally a number of long black bristles" as described by Garrett; the female has a somewhat similar comb. The parameres of the male are unique in the genus with longitudinal rather than transverse rows of setulae.

*Megophtalmidia* Dziedzicki,1889.

*Megophtalmidia marceda* (Sherman), [1921] **n. comb.**

*Tetragoneura marceda* Sherman, [1921]:20.

I have examined the holotype. The male terminalia, pleura and wing venation are typical of the genus *Megophtalmidia.*

## ACKNOWLEDGEMENTS

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# The influence of orchard ground cover and introduced green lacewings on spring populations of western flower thrips in apple orchards

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## ABSTRACT

Bare soil, grass and weedy ground covers were compared for their influence on population densities of western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera:Thripidae), within a blossoming British Columbian apple orchard. Weedy ground cover harbored the thrips before and during their movement into the apple blossoms and more western flower thrips were found in the trees in weedy ground plots than in bare soil plots during the first week of bloom. These early season differences in thrips counts did not persist through the season, and were not consistently reflected in the percent of apples damaged by the thrips. The $F_1$ generation of western flower thrips in cluster samples were lower in trees where nymphs of the common green lacewing *Chrysopa carnea* (Stephens) (Neuroptera: Chrysopidae) were introduced at bloom. The introduced lacewings did not reduce thrips damage to the apples.

**Key words:** *Frankliniella occidentalis*, thrips, apples, ground cover

## INTRODUCTION

In the Okanagan Valley of British Columbia, adult western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), overwinter in protected sites in the ground, emerging in the spring to feed on early flowering wild plants, such as arrow-leafed balsam root, *Balsamorhiza sagittata* Nutt. and saskatoon, *Amelanchier alnifolia* Fern. Adult thrips move into orchards as the apple trees begin to bloom (Madsen and Procter 1982).

Adult female western flower thrips cut pockets in epidermal apple cells while inserting the eggs into developing fruit within the blossom (Lewis 1973). The damage causes a circular discolouration of the apple skin, called a 'pansy spot', which varies in its evidence among apple varieties (Madsen and Jack 1966). Large pansy spots downgrade the quality of the apple (Madsen and Procter 1982) and more than one blemish per apple is common. To control the thrips effectively before damage occurs, chemical pesticides need to be applied when the orchard is in full bloom which could have a toxic effect on bees while they are actively pollinating the fruit blossoms. Effective thrips management techniques are needed as alternatives to chemical controls.

The potential of ground cover to influence arthropod complexes in apple orchards has been frequently addressed (Leius 1967; Gruys 1982; Hubscher 1989; Haley and Hogue 1990; Meagher and Meyer 1990; Bugg 1992). The studies were initiated with the general premise that a ground cover made up of selected plant species that are attractive to beneficial arthropods would augment the establishment of these arthropod populations. Watts (1936) however, suggested that a weedy ground cover might increase western flower thrips populations because of the attraction of the thrips to flowers and the availability of overwintering sites.

The purpose of this study was to determine if bare soil could discourage thrips entry into apple orchards relative to a grass cover, which is generally used in commercial British Columbian orchards, or a weedy cover. Early season populations of western flower thrips predators are insufficient to control the pest during bloom (Lewis 1973; Hubscher 1989). Within the ground

cover study we integrated the release of the common green lacewing, *Chrysopa carnea* (Stephens) (Neuroptera : Chrysopidae), which is indigenous in apple orchards, feeds on the thrips (Lewis 1973; Beers *et al.* 1993), and is reared commercially. The common green lacewings were released at the time of the thrips' spring orchard immigration, to observe whether the predator could effectively lower the thrips populations.

## MATERIALS AND METHODS

The floor of a 2- to 3-year-old Liberty/M9 slender spindle apple orchard was maintained in two replicates of three 25.5 x 24.5 $m^2$ sections as: 1)soil - maintained free of ground cover throughout the year with a combination of tillage, contact and residual herbicides; 2)grass - pure grass sod of perennial rye grass and creeping red fescue, maintained free of broadleaf weeds with 2,4-D and mecoprop; and 3)weedy - the same grass sod as in 2, rototilled lightly in the summer of 1994 and seeded with white clover (*Trifolium repens* L.) and a wide assortment of local broadleaf weeds including white cockle (*Lynis alba* Mill.), shepherd's purse (*Capsella bursa-pastoris* (L.)) and tumble mustard (*Sisymbrium altissimum* L.). Tree rows were maintained relatively weed-free with regular herbicide applications.

At the pink bud stage of blossom development, five (1995) and one (1996) group(s) of six adjacent trees were tagged within each treatment plot. Tagged trees were sampled for western flower thrips prior to bloom using limb-taps, and the adjacent ground covers were also sampled with sweeps to determine western flower thrips densities. In the first 1995 release, wild adult western flower thrips were included in the releases in anticipation of inadequate thrips moving naturally into the blossoms. Predators and thrips were transferred into blossom clusters using a camel's hair brush when samples in 1995 indicated that the thrips were moving into apple blossoms. For the first release in 1995, 40 adult western flower thrips collected from arrow-leafed balsam root were released alone or in combination with 20 early-instar common green lacewing (Westgro Sales, Richmond, BC) nymphs/tree. Thirty *C. carnea* nymphs/tree were again released 11 days later when wild thrips population densities were high. A control plot into which no western flower thrips or predators had been released, was included in both years of the study.

In 1995, limb-taps and cover sweeps (to sample western flower thrips populations levels), were conducted 1, 2, 5 and 10 weeks after the predators were released. Three limb-taps per tree and three cover sweeps per release site were used. In 1995 six clusters were collected per monitored tree within the first release and in 1996 fifteen clusters were collected per monitored tree 2 weeks after western flower thrips entered the orchard. The thrips were counted with the aid of a stereoscopic dissecting microscope. In both years all fruit was harvested from each monitored tree in June and thrips damage was recorded. The count included any apples dropped from the trees, as damaged fruit may be aborted (Boivin and Stewart 1982). Variation among treatments was statistically compared using ANOVA. Separate analyses were done for each date the data were collected. Means were compared using Tukey's studentized range test after arcsin transformation of the data (SAS 1985).

## RESULTS AND DISCUSSION

**Influence of ground cover.** Ground cover sweep samples of western flower thrips populations conducted in 1995 indicate that western flower thrips populations were present in the weedy ground cover before the apple blossoms opened (27 April) (Fig. 1a). Weekly thrips cover sweep counts increased within the weedy ground cover during the period of full bloom (8-15 May) . In comparison, thrips numbers in the bare soil and grass treatments remained negligible through this period and were significantly ($P<0.05$) lower compared to the weedy ground cover treatments.
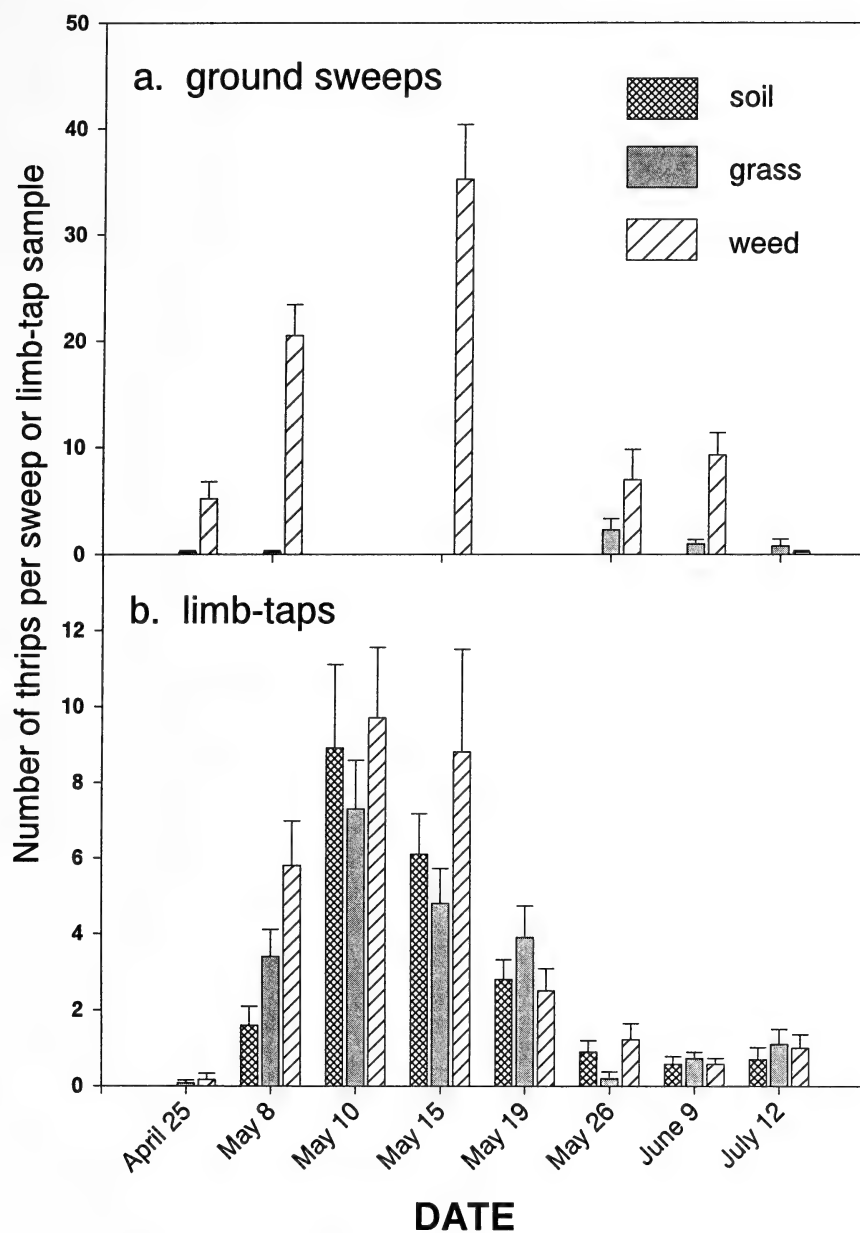
**Figure 1.** Mean western flower thrips per ground cover sweep (a) and limb-tap (b) in 1995 samples within bare soil, grass or weedy ground cover plots.

Pre-blossom limb-tap counts of western flower thrips in 1995 (25 April) were negligible for all three ground covers (Fig. 1b), indicating that large numbers of western flower thrips had not yet moved into the trees even in the weedy ground cover treatment. The limb-tap counts increased in all treatments through the period of apple bloom in a manner paralleling the sweep counts from the weedy ground cover. Limb-tap counts of the thrips from the weedy plots were generally higher than those in the soil and grass plots until petal fall (19 May); however, the

difference in the number of western flower thrips was significantly ($P<0.05$) higher in the weedy ground cover trees only once (8 May), early in the bloom period (Fig. 1b).

Counts of western flower thrips within blossom clusters in bare soil plots were significantly ($P<0.05$) lower than in both the grass and weedy ground cover treatments in 1995. In 1996 counts of western flower thrips in the blossom clusters were made 13 days later than in 1995 and those from the bare soil plots did not differ from those in the weedy and grass plots (Table 1). The mean percent of apples harvested with pansy spot damage was not significantly different among the soil, grass and weedy ground cover plots in any of the 1995 and 1996 trials (Table 2).

**Table 1**

Mean number western flower thrips per apple blossom cluster, 17 May, 1995 and 30 May, 1996. Releases in 1995: 40 western flower thrips/tree with or without 20 *Chrysopa carnea* per tree.

| Year | Introduction | Ground cover[1,2] | | |
|------|--------------|-------------------|------|-------|
| | | soil mean (n) ±SE | grass mean (n) ±SE | weeds mean (n) ±SE |
| 1995 | *C. carnea* + thrips | 3.3 (11) ± 0.54 bB | 3.8 (12) ± 0.78 bAB | 5.6 (12) ± 0.61 bA |
| | thrips | 5.4 (11) ± 0.38 aA | 7.2 (12) ± 0.61 aA | 8.0 (12) ± 1.11 bA |
| | control | 2.9 (11) ± 0.50 bB | 6.2 (12) ± 0.77 aA | 7.4 (12) ± 1.17 bA |
| 1996 | control | 4.0 (30) ± 0.65 B | 6.3 (28) ± 0.87 B | 4.9 (30) ± 0.63 B |

[1] Means within year and ground cover followed by the same lower-case letter are not significantly different (Tukey's studentized range test, $P>0.05$).
[2] Means within year and introduction followed by the same upper-case letter are not significantly different (Tukey's studentized range test, $P>0.05$).

**Table 2**

Mean percent apples with western flower thrips damage harvested in late June. Releases included: 1995i: 40 western flower thrips with and without 20 *Chrysopa carnea* /tree; 1995ii: 30 C. *carnea*/tree. Six (1995) and 15 (1996) trees sampled per plot.

| Year | Introduction | Ground cover[1,2] | | |
|------|--------------|-------------------|------|------|
| | | soil mean ±SE | grass mean ±SE | weed mean ±SE |
| 1995i aA | *C. carnea* + thrips | 14.5 ± 2.9 aA | 11.4 ± 2.8 aA | 15.1 ± 3.8 |
| | thrips | 7.2 ± 1.7 aA | 13.3 ± 3.2 aA | 13.4 ± 2.9 aA |
| | control | 15.9 ± 3.2 aA | 14.7 ± 2.2 aA | 18.9 ± 3.0 aA |
| 1995ii | *C. carnea* | 18.2 ± 4.2 aAB | 9.0 ± 2.9 aB | 26.7 ± 4.0 aA |
| | control | 10.6 ± 2.9 aA | 17.6 ± 2.2 aA | 19.3 ± 3.6 aA |
| 1996 | control | 20.6 ± 2.4 A | 20.5 ± 2.3 A | 22.6 ± 3.5 A |

[1] Means within year, trial and ground cover followed by the same lower-case letter are not significantly different (Tukey's studentized range test, $P>0.05$).
[2] Means within year and introduction followed by the same upper-case letter are not significantly different (Tukey's studentized range test, $P>0.05$).

**Influence of predator releases.** Limb-tap counts of western flower thrips did not indicate that the pest populations were significantly ($P<0.05$) lower in trees in which predators had been released. Only a few *C. carnea* were recaptured by limb-taps in 1995 despite the large numbers initially released. It is possible that the species were not effectively retrieved using this sampling technique or that the predators had dispersed from the trees.

Cluster samples were conducted sufficiently late after blossom that the collected thrips

represented the F1 generation from the damaging blossom population. In the first release of 1995, significantly fewer thrips were counted in cluster samples where the *C. carnea* and western flower thrips were released versus the clusters where only western flower thrips were released within the soil and grass ground cover plots (Table 1). However, there was no evidence of reduced apple damage in 1995 resulting from predator releases (Table 2). Temperatures during the first and second releases in the study (1 and 12 May, 1995) were low (minimum of $5^0$C). *Chrysopa carnea* prey on adult western flower thrips at $15^0$C in laboratory trials (Cossentine, unpublished data) and they may have remained inactive when temperatures were $\leq 10^0$C and fed more effectively on the subsequent $F_1$ generation.

**Indigenous beneficial arthropods.** Pre-blossom limb-taps and ground cover sweeps contained spiders ($\bar{x}$ =0.05/tree) and predaceous thrips ($\bar{x}$ =0.03/tree). There were few other arthropods found in samples until after the apples blossomed. There were no significant differences in the numbers of beneficials found during this period between ground covers.

## CONCLUSIONS

The percentage of apples damaged by the western flower thrips was high for all ground cover treatments (7.2 - 26.7%) (Table 2). The test orchard is particularly susceptible to spring western flower thrips immigration as it is adjacent to wild arrow-leafed balsam root and saskatoon bushes. Commercial apple orchards in similar situations could suffer serious economic loss due to the western flower thrips, particularly if the fruit variety did not colour sufficiently to mask the damage. The removal of wild western flower thrips hosts adjacent to most orchards susceptible to the high numbers of immigrating thrips is impractical in most situations and alternative control strategies are needed.

It has been well documented that cover crops have positive influences on orchard ecosystems. The ground cover can reduce soil erosion, influence soil nutrients and water retention and reduce soil compaction (Bugg and Waddington 1994; Hogue and Neilsen 1987). Either by providing good overwintering habitat or by enticing migration into the orchard from native plants, the weedy ground cover in this study significantly influenced the number of western flower thrips on the orchard floor. It is possible that the high numbers of thrips found resident in the weedy ground cover plots may have influenced the counts in the other two vegetation treatments. The fruit damaged by thrips in the soil or grass plots was not significantly lower than fruit damaged in the weedy plots. The positive influences of grass or weed covers on the orchard ecosystem discussed above exceed the potential of the bare soil cover to cause a small, possibly unreliable reduction of the western flower thrips damage.

Introduction of *C. carnea* nymphs into apple orchards in full bloom, to control western flower thrips during the cool spring temperatures in the southern interior of British Columbia, does not appear to be an effective thrips management strategy. The possible use of indigenous spiders and/or predaceous thrips, that appear to be active at the cool spring temperatures, should be further investigated.

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# Pre-attack systemic applications of a neem-based insecticide for control of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae)

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## ABSTRACT

An insecticide from neem, *Azadirachta indica* A. Jussieu, seeds, applied to the xylem of lodgepole pine trees at 0.05 g of the active ingredient, azadirachtin per cm diameter at breast height, reduced larval numbers and almost totally prevented successful development to adulthood of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, whether applied before or after trees were attacked. Smaller amounts of azadirachtin were less effective. Neem was effective up to the top of the beetle attack zone (4 m), indicating that the active ingredient was effectively translocated. The treatment window for applying neem systemically against this pest is longer in duration than previously thought, and pre-attack treatments can be used to create lethal trap trees.

**Key words:** neem, mountain pine beetle, pre-attack systemic application

## INTRODUCTION

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins (MPB), is the most economically important bark beetle in western North America. In British Columbia, it attacks lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann, and ponderosa pine, *P. ponderosa* Douglas ex Lawson (Unger 1993). In the Cariboo Forest Region in 1984, 405,000 ha were infested (Anonymous 1993). Current control measures include sanitation harvesting of large, infested areas, and control of spot infestations by trapping into pheromone-baited trees for later destruction. Immediate and effective control of spot infestations is essential to prevent the spread of outbreaks and their ascension to outbreak status (Borden 1993; Brooks and Maclauchlin 1994). Beetle larvae in baited trees are usually removed by sanitation cutting, or killed by winter-time "fall and burn" treatments, or by the post-attack injection of monosodium methane arsenate (MSMA). MSMA is potentially toxic to applicators and other organisms, and its mode of action remains unclear (Maclauchlin *et al.* 1988a). Naumann *et al.* (1994) reported that an insecticide extract of the neem tree, *Azadirachta indica* A. Jussieu (Meliaceae), controlled MPB when applied systemically to recently attacked lodgepole pine trees.

Extracts of neem seeds have been successfully tested for the control of many phytophagous insects (Koul *et al.* 1991; Schmutterer 1990). These extracts contain many compounds, but most of the insecticidal activity can be attributed to the tetranortriterpenoid azadirachtin (Isman *et al.* 1990). Neem is proving to be safer than most conventional insecticides for non-phytophagous insect species, including entomophagous insects (Lowery and Isman 1994; Stark 1992).

The systemic activity of neem seed extracts has been demonstrated on several pests of conifers including the MPB (Naumann *et al.* 1994), spruce budworm, *Choristoneura fumiferana*

(Clem.) on black and white spruce, *Picea glauca* (Moench) Voss and *P. mariana* (Mill.) B.S.P., respectively (Wanner *et al.* 1997), and pine false webworm, *Acantholyda erythrocephala* (L.) on red pine, *Pinus resinosa* Ait. (Lyons *et al.* 1996). In lodgepole pine, neem applied to an axe frill at the base of the tree translocated at least 9 m up the bole in amounts sufficient to disrupt the development of the pine engraver, *Ips pini* (Say) (Duthie-Holt *et al.* 1999). However, Naumann *et al.* (1996) reported only minor effects on the white pine weevil, *Pissodes strobi* (Peck) in Sitka spruce, *Picea sitchensis* (Bong.) Carr., and no effects on the same weevil species in hybrids of white spruce and Engelmann spruce, *P. engelmannii* Parry. Naumann *et al.* (1994) tested only post-attack treatments. Moreover, evaluation of efficacy by Naumann *et al.* (1994) was made low on the bole of the tree. If the treatment window could be extended by applying neem before attack by the MPB, forest pest managers would have more time to apply treatments, and treatment costs could be lowered by applying pheromone lures and insecticidal treatments to create lethal trap trees on a single visit to an infestation.

Our objectives were to determine if systemic applications of a neem-based insecticide can control the MPB if injected into pheromone-baited trees prior to beetle attack, and to evaluate the efficacy of neem near the low and high extremities of attack on the bole of lodgepole pines.

## MATERIALS AND METHODS

The neem seed extracts used in this study were formulated as emulsifiable concentrates (Phero Tech Inc., Delta, BC), and are described in terms of percent azadirachtin (Naumann *et al.* 1994). A formulation control consisted of proprietary emulsifiable concentrate without the neem extract.

**1994 Season.** On 5 July, prior to adult beetle flight at Lyne Lake, near Williams Lake, BC, baits containing MPB aggregation pheromones (Phero Tech Inc., Delta, BC, Canada) were hung 2.5 m high on the north sides of 35 lodgepole pines distributed in a grid, with baited trees $\approx 50$ m apart. Mean tree diameters were $34.1 \pm 2.1$ cm at breast height (1.3 m). Baited trees were randomly assigned to five treatment groups. Two treatments were applied to 6 trees each, prior to beetle attack: 3% neem applied into a continuous axe frill at the base of the bole (Lister *et al.* 1976), and a frill-only control. On 5 August, after beetle attack, three treatments were applied into axe frills in five trees each: 3% neem, MSMA (Glowon Liquid Tree Killer[R], Later Chemicals Ltd., Richmond, BC), and a formulation control. Neem and formulation control treatments were applied at 50 ml per tree, corresponding to 1.5 g azadirachtin per tree, or 0.048 g/cm dbh = 15 mg/cm circumference), for the neem treatment. MSMA was applied at the recommended rate of $\approx 1$ ml/2.5 cm tree circumference. Not all baited trees were successfully attacked. Therefore, the post attack groups included some nearby attacked, but unbaited trees which were randomly assigned to each of the post-attack treatments.

During 8 – 14 November, 175 cm$^2$ discs of bark were removed 10 m high from each of the test trees. The discs were cut with a gas-powered hole cutting saw, into the first layers of xylem, and pried loose using chisels so that the bark remained attached to the wood. Bark discs were stored in the dark at ca.10° C and 80% R.H. until dissected to determine the numbers of surviving and dead larvae/25 cm of adult gallery, and total lengths of adult galleries.

On 17 November, sections of the bole were cut 1 m above the frill line of each control and neem-treated tree. The 1m-long log sections were maintained in individual cages, at ca. 22° C and 12:12 L:D, and adults were collected from each cage every 2 - 3 days, until adult emergence was complete.

**1995 Season.** A second experiment was conducted at a MPB-infested site near Redeau Lake, east of 150 Mile House, BC. Pheromone baits were applied to 63 trees on 17 July, as in 1994, except that the baited trees (dbh = $29.4 \pm 0.7$ cm) were ca. 20 m apart. Trees were randomly assigned to five treatments but, as in 1994, not all baited trees were successfully attacked, and

therefore, some nearby attacked, but unbaited trees were randomly assigned to post-attack treatments. Two treatments were applied on 17 July, 2 - 5 days before MPB attack: 50 ml of 2% neem (equivalent to 1 g azadirachtin/tree = 0.034 g azadirachtin/cm dbh = 11 mg/cm circumference; n = 10), and 50 ml of a formulation control with no neem (n = 10). Three post-attack treatments applied on 22 August were: 50 ml of 2% neem (n = 8), 50 ml of 0.7% neem (equivalent to 0.35 g azadirachtin/tree = 0.012 g azadirachtin/cm dbh; n = 8), and MSMA (2 ml/cm tree circumference; n = 7).

All beetle-attacked test trees were felled on 31 October. On 4 November, two 0.5 m log sections were cut from each felled tree, one 1 - 2 m high, the other 1-2 m below the highest point of attack ($\bar{x}$ = 5.5 $\pm$ 0.5 m). The highest attacks were frequently unsuccessful. The log sections were caged, as in 1994, and the numbers of emergent adults recorded.

**Statistical Analysis.** Data, log transformed where necessary, were subjected to t-tests or ANOVA followed by Tukey's multiple comparison test using the Statistix software program (Anonymous 1991). In all cases $\alpha$ = 0.05.

## RESULTS

**1994 Season.** Pre-attack 3% neem treatments had no effect on the density of surviving larvae 3 months after application (Fig. 1), but almost completely eliminated later adult emergence (Fig. 2). Two months after application, post-attack neem and MSMA treatments reduced larval densities near the frills but had no effect 10 m up the tree (Fig. 1). Post-attack treatments of neem almost completely stopped adult emergence (Fig. 2).

**1995 Season.** Pre- and post-attack treatments of 2% neem both reduced numbers of emerging adults, although the reduction was not as overwhelming as seen with a 3% formulation in 1994 (Fig. 3). Post-attack treatments with 0.7% neem had no significant effect. The relative levels of reduced emergence induced by the different treatments were similar at the bottoms and tops of the attack zones.

## DISCUSSION

Our results corroborate those of Naumann et al. (1994), demonstrating a reduction in larval MPB densities 3 - 4 months after systemic neem application, followed by a much greater reduction in later adult emergence. Moreover, they demonstrate that the active ingredients in the neem seed extract were translocated, in effective amounts, to the top of the attack zone, supporting the results of Duthie-Holt et al. (1999) with trees felled 1 week after treatment and then infested by I. pini. The absolute numbers of adults emerging from neem-treated trees were always greater than those from trees treated with MSMA, although the differences were not significant. Our results, plus those of Naumann et al. (1994), Duthie-Holt et al. (1999), and Naumann (unpublished data), indicate that the delivery of at least 0.05 g of azadirachtin per cm tree diameter at breast height is required to give a level of control comparable to that of MSMA.

Lastly, our results demonstrate that pre-attack treatments of neem with 3% azadirachtin are as effective as post-attack applications, suggesting that the window of application can be extended to several days before peak adult flight. In this respect, neem is superior to MSMA, which must be applied post-attack because it repels adult MPB (Maclauchlin et al. 1988b) and would therefore disperse them to untreated trees. The neem treatments did not appear to repel adults, supporting Duthie-Holt and Borden's (1999) finding that trees sprayed with a 0.2% neem formulation were attacked by the MPB within 24 h of application.
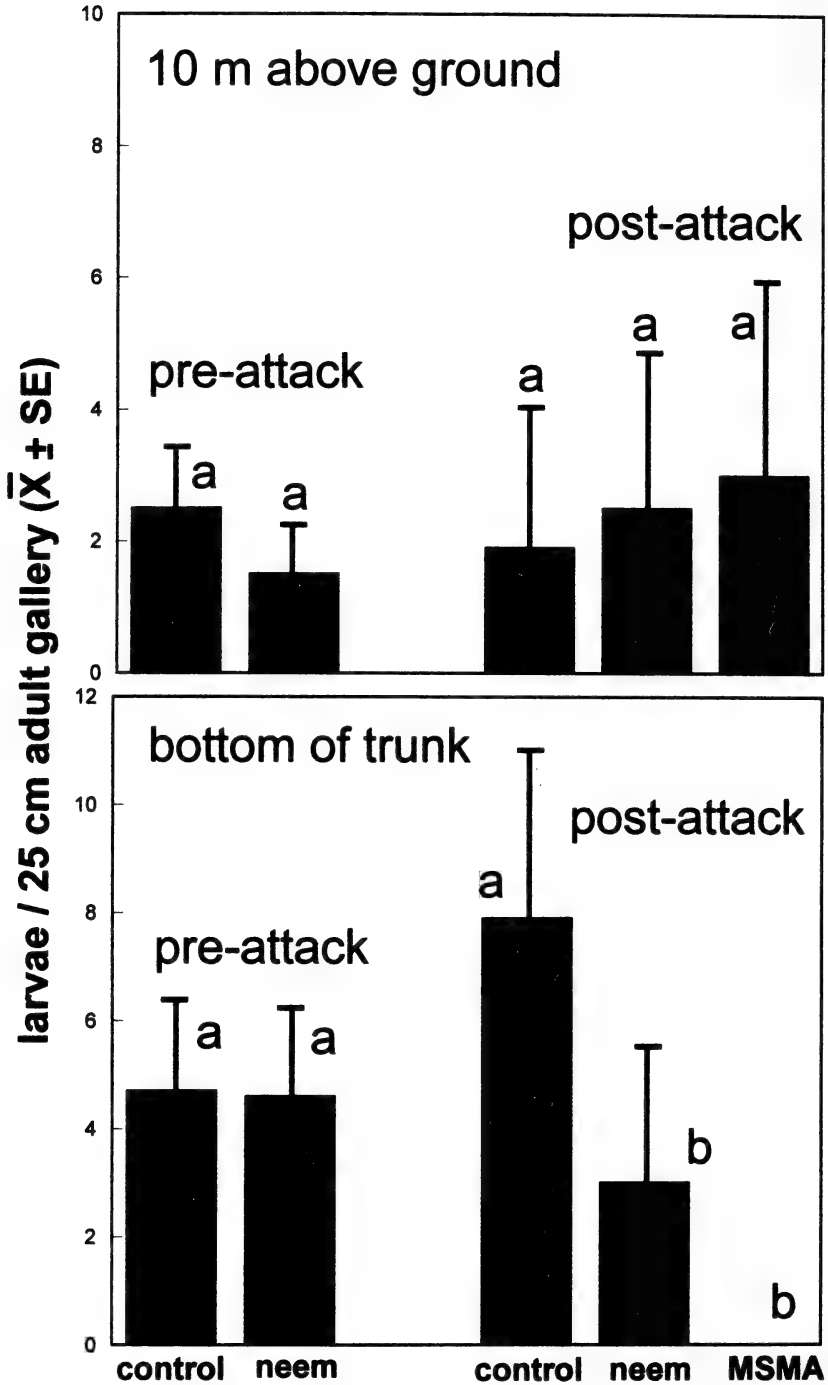
**Figure 1.** 1994 Season. Number of surviving mountain pine beetle larvae per 25 cm of adult gallery length in lodgepole pine trees 3 months after systemic application of 50 ml of neem (3% azadirachtin), MSMA, or a control solution. Bars within pre- or post-attack treatments with the same letter are not significantly different (Tukey's test, $P > 0.05$).
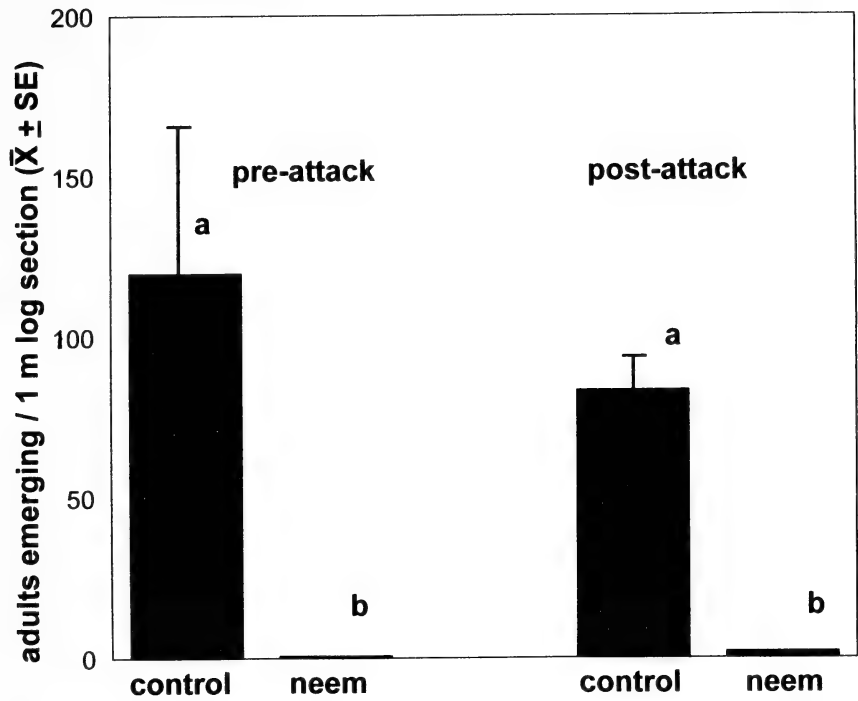
**Figure 2.** 1994 Season. Number of adult mountain pine beetles emerged from 1 m log sections following systemic applications of neem (3% azadirachtin) or a formulation control. For each treatment time, bars with the same letters are not significantly different ($t = 2.37$, df = 10, $P = 0.04$ for pre-attack treatment, and $t = 6.44$, df = 9, $P = 0.0001$ for post-attack treatment).

We did not assess the age at which mortality occurred, nor the direct cause. It is probable that high doses of azadirachtin ingested by larvae near the axe frills had an acutely toxic effect. Azadirachtin is well known to produce morphological deformities in many insect taxa (Mordue and Blackwell, 1994). Similarly, the survival of larval MPBs (Fig. 1) (Naumann *et al*. 1994) and pine engravers (Duthie-Holt *et al*. 1999) followed by failure of adult emergence suggests that the efficacy of neem against bark beetles lies in a late larval or pupal developmental effect. These results, plus the finding that systemic neem applications had no effect on *D. ponderosae* larval weights (Naumann *et al*. 1994) and that attack occurred on freshly sprayed bark (Duthie-Holt and Borden 1997) indicate that feeding inhibition is not an important cause of mortality in bark beetles.

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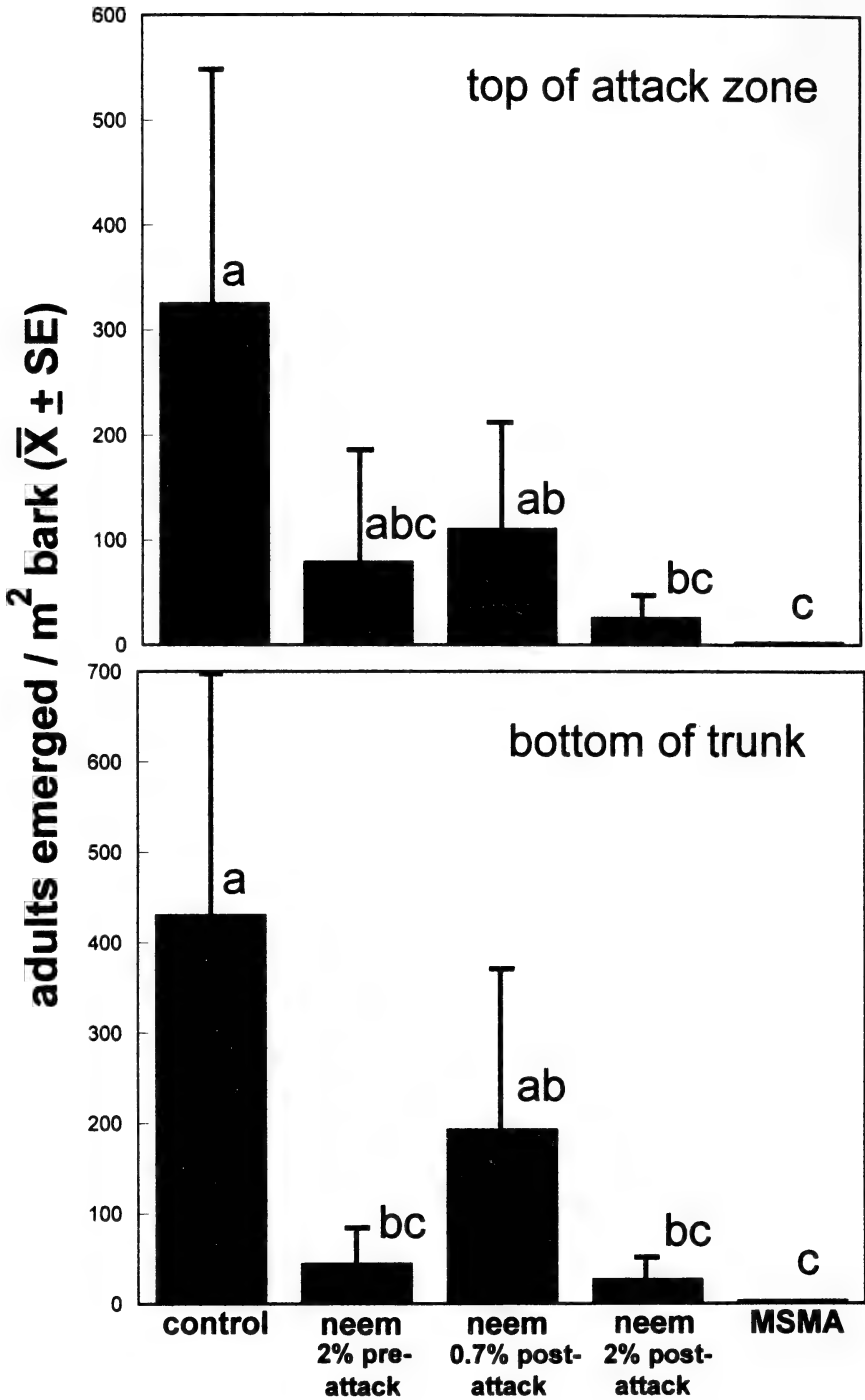
**Figure 3.** 1995 Season. Numbers of adult mountain pine beetles emerged per m$^2$ of bark from trees given pre- or post-attack 50 ml systemic applications of neem (2% azadirachtin applied before beetle attack, or 0.7% or 2% azadirachtin applied post-attack), MSMA, or a formulation control. Bars, within an attack zone, with the same letters are not significantly different (Tukey's test, $P > 0.05$).

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# Treatment of lodgepole pine bark with neem demonstrates lack of repellency or feeding deterrency to the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae)

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## ABSTRACT

Recent research indicates that development of coniferophagous bark beetles can be severely disrupted by systemic applications of extracts from seeds of the neem tree, *Azadirachta indica* A. Jussieu. However, the potential for neem to repel or deter feeding has not been determined. Surface treatment to the run-off point with a neem-based insecticide (2,000 ppm azadirachtin in 10% emulsifiable concentrate in water) to the boles of attractant-baited lodgepole pines, *Pinus contorta* var. *latifolia* Engelmann, was ineffective at repelling or deterring attack by the mountain pine beetle, *Dendroctonus ponderosae* Hopkins. Therefore, the activity of neem against the mountain pine beetle is limited to that of a systemically-applied insect growth regulator.

## INTRODUCTION

Recent research on direct control of bark beetles (Coleoptera: Scolytidae) has focused on extracts from seeds of the neem tree, *Azadirachta indica* A. Jussieu (Meliaceae). When emulsifiable concentrates of neem seed extracts were applied at doses $\geq 15$ mg per cm of circumference into axe frills at the base of lodgepole pines, *Pinus contorta* var. *latifolia* Engelmann, almost complete disruption of development to adults was achieved by systemic action for both the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Naumann *et al.* 1994; Naumann and Rankin 1999), and the pine engraver, *Ips pini* Say (Duthie-Holt *et al.* 1999). Because both species freely attacked neem-treated trees, successfully established galleries, and produced brood larvae that appeared to be unaffected as early instars, it is unlikely that neem applied to axe frills had any repellent or antifeedant activity.

However, against many other insects, neem acts as a repellent and a feeding deterrent (Mordue and Blackwell 1993), rendering plants unattractive or unacceptable to insects. The feeding deterrent effect of neem is caused by the principal active ingredient azadirachtin (Blaney and Simmonds 1995), the most potent natural insect antifeedant discovered to date (Isman *et al.* 1991).

Our objective was to determine whether neem applied externally to the bark of lodgepole pines had any repellent or feeding deterrent activity against the mountain pine beetle.

## MATERIALS AND METHODS

Forty-five uninfested lodgepole pines (mean diam. at 1.3 m = 27.3 ± 3.6 cm) were selected at 25 m intervals in a heavily-infested mature stand on Commander Road, in the Willis Creek drainage, ca. 26 km south of Princeton, BC. The trees were randomly assigned to one of three treatment groups; untreated control, formulation control (10% emulsifiable concentrate formulation in water, with no neem), and neem (2,000 ppm azadirachtin in 10% emulsifiable concentrate formulation in water). The proprietary control and neem formulations were supplied by Neem International Enterprises Inc., Surrey, BC. Two separate back pack sprayers, each with 1.5 m wand extensions and flat fan nozzles, were used to apply the control and neem treatments. On 25 July 1996 trees were sprayed to the run-off point with 1.0 to 1.3 L treatments from the root collar to approximately 5 m up the bole around the entire bole circumference. Tree baits (Phero Tech Inc, Delta, BC), releasing the aggregation pheromones *exo*-brevicomin and *trans*-verbenol (Borden *et al.* 1993) were then stapled approximately 1.5 m high on the north face of each of the 45 trees to challenge mountain pine beetles to attack the trees.

On 26 July, 1 August, and 7 August 1996 all trees were examined, and classed as mass attacked if there were ≥ 5 entrance holes in total in two 20 x 40 cm areas at eye level on the east and west faces of the tree (≥ 31.25 attacks per $m^2$) (Borden *et al.* 1983). In October 1996, 20 x 20 cm bark samples were removed at eye level from the east and west faces of each tree. The exposed entrance holes, egg galleries, and larvae were counted, and the total length of egg galleries in each sample was measured. The data were analyzed by ANOVA using general linear models ($\alpha = 0.05$) (SAS Institute Inc. 1988).

## RESULTS

The neem formulation had no effect on mountain pine beetle attack when applied as a spray to the bole of lodgepole pines. When some of the treated trees were inspected at 1900 h on 25 July, ca. 3 h after treatment, most were already under attack, as evidenced by beetles walking on the bark surface and beginning to bore entrance holes. At that time the neem odor was very evident to the authors. All 45 trees were attacked within 1 day of treatment, and confirmed as mass attacked 1 week later. There were no differences between treatments in attack densities, lengths of egg galleries, or numbers larvae per $m^2$ (Table 1).

## DISCUSSION

Neem-induced repellency and/or feeding deterrency occurs in six families of Coleoptera (Schmutterer 1995), including the Scolytidae (Sponagel 1993). However, no such effects were seen in our experiments with an emulsifiable-concentrate formulation sprayed on the bole.

Any possible repellency was surmounted, apparently within 3 h, by beetles orienting to and attacking attractant-baited trees, regardless of the neem treatment. At a dose of 2000 ppm azadirachtin with 1.0-1.3 L applied to the lower 5 m of a perfectly cylindrical tree bole with a 27.3 cm diameter, there would be 2.0-2.6 g of active ingredient per tree, or 0.047-0.061 mg per $cm^2$ of bark. In comparison, if neem applied at a dose of 1.5 g per tree were to be systemically translocated evenly throughout the lower 10 m of the bole of a perfectly cylindrical tree with a 31.4 cm diameter (Naumann and Rankin 1999), there would be at most 0.015 mg of active ingredient per $cm^2$ of inner bark, 3-4 times lower than on the bark surface in our experiment. Because azadirachtin translocates rapidly in conifers (Naumann *et al.* 1994), it would probably lodge in the upper bole or foliage, as does the arsenical monosodium methane arsonate (Maclauchlan *et al.* 1988), making the

**Table 1**

Summary of mountain pine beetle attack characteristics on untreated lodgepole pines, trees sprayed to the run-off point with a formulation control (10% proprietary emulsifiable-concentrate formulation diluted with water), or trees sprayed with neem (2,000 ppm azadirachtin in a 10% emulsiable-concentrate formulation). Commander Road, near Princeton, BC, treated 25 July 1996, 15 trees per treatment. Data from bark samples taken on 8 and 20 October 1996.

| Treatment | Criteria measured[a] | | | |
|---|---|---|---|---|
| | Attack density per m$^2$ ($\bar{x}$ ±SE) | Number of egg galleries per m$^2$ ($\bar{x}$ ±SE) | Length of egg gallery (cm) per m$^2$ ($\bar{x}$ ±SE) | Number of larvae per m$^2$ ($\bar{x}$ ±SE) |
| Untreated Control | 127.5 ± 16.5 | 345.0 ± 30.0 | 4271.3 ± 463.5 | 1505.0 ± 347.1 |
| Formulation Control | 126.7 ± 11.3 | 348.3 ± 25.3 | 4298.8 ± 448.3 | 1895.0 ± 325.3 |
| Neem | 155.8 ± 13.6 | 336.7 ±24.9 | 4182.8 ±401.3 | 1866.7 ± 278.3 |

[a]No significant difference between means within any column, GLM test, $P>0.05$.

actual residual dose in the phloem of the lower bole much less than 0.015 mg per cm$^2$. Mountain pine beetles characteristically walk extensively on the bark of lodgepole pines before beginning boring activity. Therefore they would be even more likely to experience a high dose of neem following a surface application to the bark than they would in the phloem of a systemically treated tree. Typically, feeding deterrent activity occurs at <1-50 ppm azadirachtin in Lepidoptera, 100-600 ppm in Coleoptera, Hemiptera and Homoptera, and 0.05-1000 ppm in Orthoptera (Modue and Blackwell 1993), in each case far lower doses than the 2000 ppm applied in our experiment.

Our results constitute strong evidence for the lack of neem-based repellency or feeding deterrency for the mountain pine beetle. Naumann and Rankin (1999) found high larval mortality just above the axe frill of systemically-treated trees, suggesting some degree of acute toxicity at high doses of neem. However, the results of this study, as well as those of Naumann *et al.* (1994), Duthie-Holt *et al.* (1999) and Naumann and Rankin (1999) demonstrate that neem must act on the mountain pine beetle primarily as an insect growth regulator.

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# Laboratory rearing of the eastern hemlock looper (Lepidoptera: Geometridae) on artificial diet and grand fir foliage

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## ABSTRACT

This paper describes a technique to rear the eastern hemlock looper, *Lambdina fiscellaria fiscellaria* (Guen.) on a modified spruce budworm artificial diet and foliage of grand fir, *Abies grandis* (Dougl. ex D.Don).

**Key words:** *Lambdina fiscellaria fiscellaria, Abies*, artificial diet, rearing

## DISCUSSION

The eastern hemlock looper, *Lambdina fiscellaria fiscellaria* (Guen.), is distributed from Newfoundland to Alberta in Canada, and is a serious forest pest in mature stands of balsam fir, *Abies balsamea* (L.), and eastern hemlock, *Tsuga canadensis* (L.) Carrière. To ensure a continuous and qualitatively uniform supply of this insect for research, efficient and reliable laboratory rearing techniques are needed. Larvae can be successfully reared by feeding early larval instars CSM (corn, soy flour and milk solids) artificial diet, and later instars foliage of balsam fir (Grisdale 1975, 1985); however, the lack of availability of balsam fir in western Canada presents a major problem in the laboratory rearing of this species there. Here we describe rearing procedures for eastern hemlock looper, using a spruce budworm artificial diet (Robertson 1979) without formalin, for the first two instars, and foliage of grand fir, *A. grandis* (Dougl. ex D. Don) for later instars. The modified artificial diet was used in this study because of its availability in our laboratory. The grand fir is in the same genus as the balsam fir, a primary host of eastern hemlock looper, and available near our laboratory.

Cheesecloths with eggs of eastern hemlock looper were placed inside of sealed plastic bags that were placed inside of paper bags. To satisfy diapause requirements, eggs on the cheesecloth were stored in darkness at $2 \pm 0.5^\circ$C, 100% RH for a minimum of 3 months. After diapause, eggs were moved to an insect rearing room with conditions of $20 \pm 1^\circ$C, 55-60% R.H., and 16:8 h (L:D). The cheesecloths with eggs were sprayed with distilled water twice before larval hatching. Approximately 9 days after being moved to the rearing room, the eggs started hatching and most of them hatched over 2-4 day period. Over 90% of the eggs hatched.

Newly hatched larvae were transferred with a camel's-hair brush into 20-ml creamer cups, at the rate of five larvae per cup. Each cup had previously been half-filled with the artificial diet (Table 1). Larvae in the cups were kept at the above rearing conditions for 2 weeks, and then transferred to rearing containers filled with one-year-old grand fir foliage. The survival of neonates on the artificial diet was greater than 90%, and cannibalism in the cups was lower

than 10% when the late-second-instar larvae were transferred onto grand fir foliage. After transfer, late-second-instar larvae accepted both dormant and new, flushing grand fir foliage, however, larval survival on new foliage was higher [about 90% ($n = 455$) versus 70% ($n = 470$), $t_{18\ df} = 10.54$, $P < 0.01$]. A single young grand fir tree (about 1 m high) in a cage (0.8 x 1.0 x 1.5 m) provides enough food for 100 late-second-instar larvae to develop to pupae. Rearing eastern hemlock looper larvae on young caged trees greatly reduced labor by eliminating foliage changes, and minimized injury to larvae due to handling. This technique depends upon availability of young trees. If young flushing trees are not available, larvae can still be reared on one-year-old grand fir foliage collected from the field. Under the rearing conditions we used, larval development was uniform and completed in about 45 days.

**Table 1**

Ingredients of an artificial diet for neonate larvae of *Lambdina fiscellaria fiscellaria*[1]

| Ingredients | Quantity/batch (1000 grams of diet) |
| --- | --- |
| Agar solution | |
| Distilled water | 620.0 ml |
| Powder agar | 27.0 g |
| Dry ingredients | |
| Casein (vitamin-free) | 39.0 g |
| Cellulose (fiber) | 6.0 g |
| Salt mix, Wesson | 10.0 g |
| Sucrose | 29.0 g |
| Methyl parahydroxybenzoate | 1.7 g |
| Ascorbic acid (vitamin C) | 4.0 g |
| Sorbic acid | 1.2 g |
| Aureomycin (5.5% chlorotetracycline) | 0.93 g |
| Vitamin mix Vanderzant-Adkisson | 12.0 g |
| Wheat germ | 33.0 g |
| Liquid ingredients | |
| Distilled water | 167.0 ml |
| Potassium hydroxide (4M) | 6.7 ml |
| Raw Linseed oil | 2.0 ml |

[1] Agar solution was autoclaved for 20 min before being poured into a running blender that contained dry and liquid ingredients. The diet was dispensed into 20-ml creamer cups manually before it cooled. One batch of the diet will supply about 90 cups, if each is half filled. After cooling, diet in the cups was sprayed with an anti-fungal solution (1.5 g sorbic acid and 0.6 g methyl parahydroxybenoate in 100 ml 95% ethyl alcohol). Cups with diet were stored at 4°C for up to 5 days before being fed to larvae.

Upon pupation, the pupae were separated by sex according to Grisdale (1985), and placed in petri dishes. Male pupae were held at 4°C for 4 days to synchronize emergence with females, and then joined females at the same conditions as those of the larvae. Forty pupae (20 of each sex) were placed on the bottoms of cardboard ice cream cartons (30 cm diam by 45 cm height) with the open tops covered by five layers of cheesecloth held in place by rubber bands. After adult emergence had begun, an 8% sugar solution was provided. Adult emergence was 100% in our rearing. The emerging adults were held under the same rearing conditions as the larvae. The cartons served as mating cages and the females laid their eggs on the cheesecloth. The cheesecloths were sprayed with distilled water once or twice a day to maintain high humidity inside of the cartons. Adults survived for 3-4 weeks. After all adults had died, the cheesecloths were removed and placed at the same conditions as larvae for 1

week before sealing them inside a plastic bag. The plastic bags were then placed inside paper bags and stored in darkness at $2 \pm 0.5°C$, 100% RH. Eggs kept at these conditions for 3-6 months can break diapause and be ready for future research. Using the above-described procedures, we can readily rear more than 3000 larvae at a time.

## ACKNOWLEDGEMENTS

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# An annotated checklist of the ants
# (Hymenoptera: Formicidae) of British Columbia

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## ABSTRACT

This paper lists the ant species reported from, or likely to be found within British Columbia. Localities are given for each species, as are ecological notes and keys to the reported subspecies, genera, and species.

## INTRODUCTION

The ants of British Columbia have been surprisingly poorly studied, despite their ubiquitousness. Buckell (1927, 1932) produced two checklists of species collected in BC, however few areas of the province were surveyed and some of the listed species have been reclassified or may have been misidentified. Blacker (1992) presented a more detailed list of species personally collected near Victoria, and Blades and Maier (1996) made an extensive collection of arthropods, including ants, on Mt. Kobau, near Osoyoos. Beyond these, researchers are left with lists from nearby provinces and states including southern and central Alberta (Sharplin 1966), the Yukon (Francoeur 1997), Washington (Smith 1941), Idaho (Yensen *et al.* 1977), Montana (Wheeler and Wheeler 1988), and Alaska (Nielsen, 1987). This paper provides an introduction to the ant species reported to occur, or likely to be found, within BC. Ecological notes and localities are also given and keys are provided for species reported from within BC.

The list of BC ant species and their localities was compiled from a number of sources, including literature references, from preserved specimens in institutional collections, and the personal collections of the authors.

Keys were modified from those of Hölldobler and Wilson (1990; subfamilies and genera), Creighton (1950; most species), Wheeler and Wheeler (1986; many species), Francoeur (1973; *Formica fusca* group), (Wilson 1955; *Lasius*), and (Snelling 1973; *Stenamma*). Where possible, these keys were checked for ease of use against identified specimens.

Ant systematics are rife with synonomies and taxonomic disagreements and the taxonomy of several of the most common genera in the province, such as *Myrmica*, *Leptothorax*, and *Formica* are particularly messy. For example, *Leptothorax muscorum* is treated here as a single species but actually represents a complex of closely related species. As a result, literature outside of the most recent revisions may be misleading. For the most part, we have used the nomenclature of Bolton (1995) and Smith (1979) and mostly avoided the use of subspecific names, although they are common in the older literature. Lists of synonomies, useful especially for disentangling older literature, can also be found in the above-mentioned references.

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[1] This paper is dedicated to Gordon Ayre who passed away during the preparation of the manuscript.

British Columbia encompasses a greater range of landforms and climates than any other province in Canada. The landforms can be roughly grouped into a series of parallel systems that run northwest to southeast. Weather systems, moving predominantly from the west, interact with the parallel mountain systems to produce wet belts and rain shadows. This variability of climate, combined with diverse topography and a wide range of latitude, produce twelve distinct biogeoclimatic zones within the province (Farley, 1979; Krajina, 1959) and a wide range of potential habitats for ant species.

## ANNOTATED LIST OF BC ANTS

Localities are referenced by author or by the location of preserved specimens, i.e., UBC = the Spencer Entomology Museum at the University of British Columbia; the Canadian National Collection (CNC); the Wallis Museum, Entomology Dept., University of Mantioba, Winnipeg (WM; mostly collected by G. L. Ayre); the Royal British Columbia Museum in Victoria (RBCM); and the collections of the authors, e.g. GLA = G. L. Ayre; KN = K. Naumann; WBP = W. B. Preston. When several localities are given for a species they are listed by region, and in the following order: Vancouver Island and the Gulf Islands, the Lower Mainland, The Southern Interior, the Columbia and Kootenays, the Cariboo-Chilcotin, and the North. Species denoted by * have not been reported from BC, but have from neighbouring areas. Species denoted by **, although reported from BC, may have been accidentally imported or misidentified in the literature.

Most of the anatomical terms used in this paper are diagrammed in Figures 1 and 2. Others are explained in the text. Approximate sizes are described as follows: minute = less than 2 mm long; small = 2-4 mm; medium = 4-6 mm; large = 6-8 mm; and very large = greater than 8 mm. The descriptions of behaviour include some terms which may be new to those unfamiliar with social insects. For example, polygynous species are those that can have more than one queen per colony. Absconding is the rapid removal of the colony to a new location. Polymorphism is the occurrence of more than one size category or morphological worker caste in a nest. The largest workers are called majors, or soldiers if they specialize in defense of the nest, and the smaller workers are called minors. Cleptobiotic species rob the food stores or scavenge from the refuse piles of another species but do not necessarily nest in close association with it. Xenobiotic species, also known as guest ants, live in the nest of host species and obtain food from them but generally keep their brood separate. Inquilines, also known as a permanent or obligate social parasites are queens that spends their entire life cycle in the nest of a host species; host workers care for the queen's reproductive offspring. Such parasitic species may produce few or no workers of their own. Temporary social parasitism occurs when a queen usurps the nest of a host species. Eventually her daughters replace the host workers. Dulotic, or slave-making, species raid the nests of other species, capture brood and rear them as enslaved nestmates. Nest budding is a form of colony multiplication in which one or more queens and a subgroup of workers leave an established nest to found another nearby. For a more detailed glossary of terminology see Hölldobler and Wilson (1990).

**Ponerinae**
*Amblyopone*
Members of this genus are found in wooded areas, especially where well shaded. They are generally subterranean. The workers are timid and slow moving, and the queen forages when nest founding. There are no distinctive worker castes, and the stinged workers resemble the always wingless queens.

*A. oregonensis* Wheeler: Found at low elevations near the coast. Small to medium-sized, dark

brown predators.
**Localities**: Galiano Island (UBC); Yale - in a rotten Douglas fir stump in dense forest (WM); Washington (Smith 1941).

## Myrmicinae
### Myrmica
Members of this genus live in moderately-sized colonies of 500-1500 workers, building their nests in soil, rotten wood, or under objects. They are carnivores and/or collectors of honeydew. Many species from northern North America are closely related to Palearctic species. As a rule, they are inoffensive ants and will flee when disturbed. Undisturbed workers are rather sluggish. As in all the Myrmicinae, the pupae are never enclosed in cocoons. The following species are characterized by a dull head and alitrunk and a strongly shining gaster.

*__*M. alaskensis*__ Wheeler: Typical of the transcontinental boreal forest. Nests mostly in dead wood. Medium-sized. Some authorities consider this to be a variety of *M. incompleta*. This species acts as the host of the xenobiotic species, *Formicoxenus quebecensis* and individuals of the latter have been collected at Overlander Falls, along the upper Fraser River, and *M. alaskensis* itself has been found at several localities near Jasper, Alberta (Buschinger *et al.* 1994). Reported also from the Yukon (Francoeur 1997) and Alaska (Nielson 1987).

*__M. brevispinosa__* Wheeler: Nests in open sandy habitats, often near stream valleys or the shores of permanent water bodies. Head dark reddish-brown to yellowish-red, alitrunk yellowish-red, gaster very dark red to dark reddish-brown. Small to medium sized.
**Localities**: North Vancouver (WM); Summerland (WM); Oliver (WBP); Kamloops; Chilcotin region; Cariboo region (Buckell 1932). Also reported from Alberta (Sharplin 1966); Alaska (Nielsen 1987); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

*__M. latifrons__* Stärke: Referred to *M. emeryana* Forel in most of the literature. Head and alitrunk coarsely rugose and reddish-brown. Gaster may be slightly darker. Medium sized (4-4.5 mm).
**Localities**: Victoria (Blacker 1992); Lytton (RBCM); Osoyoos (between 800 and 1500 m elevation) (Blades and Maier 1996, listed as *M. tahoensis*). Also reported from Alberta (Sharplin, 1966); Idaho (Yensen *et al.*, 1977) and Montana (Wheeler and Wheeler 1988).

*__M. incompleta__* Provancher: Forms large, polygynous colonies in moist, grassy habitats, or at forest or bog edges. Head and gaster dark and with coarse sulcations (grooves). Medium sized ants (4 - 6 mm long).
**Localities**: Victoria (Blacker 1992); Lens Creek, Mesachie Lake - in a log (RBCM), Mission (UBC); Sicamous - nest in soil in a meadow; Field - under a stone in dense forest (WM); Flathead (WBP); Minnie Lake (Buckell 1932); Westwick Lake.; Stanley (in the Cariboo region); Lac La Hache (RBCM); Blue River (WPB). Specimens of *M. incompleta* have also been collected in the Rocky Mtns and Peace River region of Alberta (Sharplin, 1966); in the Yukon (Francoeur 1997), Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

*__M. lobifrons__* Pergande: Nests in and near boreal bogs or other moist areas that are temporarily flooded, or riverbanks. Workers are small with reddish-black gaster and head and reddish-yelolow to dusky red alitrunk. Listed from the Yukon (Francoeur 1997) and reported to occur from New Mexico and Nevada to Alaska (Wheeler and Wheeler 1986).

### Manica
These ants build small colonies in openings in coniferous forests, often under stones in or near

creeks or river bottoms.  Underground galleries are often connected to the surface by holes in the bottom of one or more small craters.  Workers usually have an orange color and will bite or sting in defense of the nest.  They have an unhurried but not sluggish gait.  Their food source is unknown, but Wheeler and Wheeler (1986) suggest that they feed on ants of other genera.

*M. hunteri* (Wheeler):  Nests in openings in coniferous forests.  Concolorous, yellowish-red to dark reddish brown, with a dull head and alitrunk and strongly shining gaster.  Medium-sized to large ants (5 - 7 mm).
**Localities**: Fruitvale - nest under a stone, surrounded by sand, in a larch/spruce forest (WM).  Also reported from Alberta (Sharplin 1966); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

*M. invida* Wheeler:  Referred to as *M. mutica* (Emery) in most of the literature.  This species is more xerophilous than most members of this genus and prefers unshaded nest sites.  Found mostly in the drier regions of southern BC, although there is also a report from Alaska (Wheeler and Wheeler 1986).  Capable of inflicting a painful sting, but rarely does unless the nest is disturbed.  Small to medium-sized. Concolorous yellowish-red to dark reddish-brown.  Head and alitrunk dull, gaster strongly shining.
**Localities**:  Summerland - tunnelled into the exposed gravel bank of a creek (WM); Oliver (WBP).  Also reported from Alberta (Sharplin 1966) and Idaho (Yensen *et al.* 1977).

### *Pogonomyrmex*
Also known as harvester ants, this group is widespread throughout southwestern North America, but is poorly represented in BC.  They collect seeds.  Nests are built in soil, fully exposed to the sun.

*P. salinus* Olsen: (= *P. owyheei* Cole)  Nests are conical pebble mounds, with basal entrances and peripheral clearings.  They are usually about 50 cm across at the base, and low. These ants are active harvesters that store and eat large quantities of seeds.  A dump of chaff can often be seen at the edge of the nest.  The workers are pugnacious and can inflict a painful sting.  They are medium-sized to large and brown to red in colour.
**Localities**: At low elevation sites in the Okanagan south of Penticton (Buckell 1927); specifically Osoyoos; Oliver; Keremeos (Buckell 1932; Blades and Maier 1996; WBP).

### *Stenamma*
Members of this genus usually form colonies of several dozen individuals in wooded areas, beneath logs, stumps, branches, rocks, moss or debris.  They feed mostly on other arthropods.  Workers are sluggish, timid, and rarely seen outside of the nest.

*S. diecki* Emery:  Nests, usually of about 100 workers, are found in rotten wood or under objects, often in shaded sites.  They are adapted to various habitats - Blacker (1992) reported that they can be found in red cedar forests.  These are small ants (3.5 mm), slender, and dark reddish brown.  Head dull, alitrunk moderately shining, and  gaster strongly shining.
**Localities**: Victoria; Thetis Island (Blacker 1992); Yale - nest under the bark of a rotting stump in dense deciduous forest (WM).  Also listed from Idaho (Yensen *et al.* 1977) and Washington (Smith 1941).

*S. occidentale* Smith: Bolton (1995) suggested that this species should be called *S. snellingi*.  Nests in soil, under rocks.  Workers are small and reddish-brown.  Stated to occur in BC by Smith (1979); in Idaho by Yensen *et al.* (1977) and Snelling (1973), and in Washington

(Snelling 1973).

**\*\*S. brevicorne** Mayr:  Quoted by Buckell (1927) (as *S. neoarcticum*) as occurring in BC, but Smith (1979) considers this small-workered species to occur east of Colorado. Smith (1957) shows the westernmost occurrences in Nebraska and Minnesota. Gregg (1963) lists this species from Colorado.

## *Aphaenogaster*

Most *Aphaenogaster* species nest in the soil beneath some protecting object.  They are predominantly carnivores, and also show rapid and well-organized absconding behavior in the presence of a major threat from enemies or flooding.  They can be distinguished from *Myrmica* species by possessing unpectinated (non-comb-like) spurs on the hind tibiae (*Myrmica* spurs are comb-shaped) and their colonies are also usually more populous (Cole 1942).  *Aphaenogaster* workers are more slender and shining.  Workers are most often seen above ground in the evening.

**A. occidentalis** Emery: It usually prefers open and dry nest sites, forming nests of several hundred individuals.  Workers are slow moving and may hide when disturbed.  They are small to medium-sized (4-5 mm), brown to reddish brown, with head dull, or the posterior portion shining, alitrunk feebly shining, and the gaster strongly shining.
**Localities**: Victoria; Thetis Island (Blacker 1992); Vancouver (UBC); Yale; Lytton; Lillooet (CNC); Osoyoos (below 1500 m, Blades and Maier 1996; WBP); Westbank - under a stone in open ground (WM; WBP); Summerland; Oliver; Savona; Anarchist Mountain - under a stone in open fir and pine forest; Kalamalka Lake (WM); Lower Nicola (WBP); Kamloops (Buckell 1932); Balfour (WBP); Slocan district (UBC); Trail; Waneta (WM); Chilcotin region (Buckell 1932).

## *Pheidole*

These ants are mainly seed harvesters, and although the genus includes many species, they are found predominantly in the arid southwest of North America.  The majors characteristically have very large heads, and may act as seed huskers or soldiers.  Colonies usually contain less than 300 individuals and are found in the soil, either under stones or without cover.

**P. californica** Mayr:  Nests under objects. Major workers are small and vary from concolorous yellow to bicoloured with head and alitrunk red and gaster dark-reddish brown.  Minor workers are minute (<2 mm), and bicoloured.  Both worker classes are shining.
**Localities**:  Osoyoos (Buckell 1927; UBC). Blades and Maier (1996) report *Pheidole* sp. from Osoyoos (probably *californica*?). Listed from Washington by Smith (1941).

## *Monomorium*

These are small ants, adaptable with respect to nesting sites.  They may nest in preformed cavities such as openings in plant litter or rotting wood or spaces in the walls of buildings.

**M. pharaonis** (Linnaeus):  This is a tramp species, i.e., widely distributed because of human commerce and living in close association with humans, and a notable house pest that probably arrived in North America from Africa or tropical Asia. Workers are small, stingless, and the colour is light reddish-yellow to brown with the gaster somewhat darker.  The head and alitrunk are densely punctate (covered with minute pits).  Multiqueen colonies can contain up to 300,000 workers.  It is a common pest in apartments in Vancouver.

**\*M. minimum** (Buckley): Although Smith (1979) states that this small ant is rare or absent from

the Pacific Northwest, it has been reported from Alberta (Sharplin 1966); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

### *Solenopsis*

These ants are often small and lestobiotic (living in, and stealing from, the nests of other species). The group includes a notable pest, the fire ant, *S. invicta*, an import from Brazil, which has become an agricultural and public health problem in the southeastern United States.

**S. molesta** (Say): A lestobiotic species that occasionally infests houses, establishing nests in woodwork and masonry. They are omniverous and will eat insects, seeds, and honeydew, as well as meats, bread, grease, fruits, nuts, and sweets. Strongly shining, minute ants (approximately 1.3 mm long), mostly reddish-brown in color.
**Localities**: Osoyoos (WM; Buckell 1932), below 800 m (Blades and Maier 1996); Westbank - under stones, tunnelled into soil, and in creek banks; Summerland - taken with an excavated nest of *Manica mutica*; Oliver; Lillooet (WM); Flathead (WBP). Buckell (1927) reported this insect to be common throughout BC. Also reported from Alberta (Sharplin 1966); Alaska (Nielsen 1987); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

### *Leptothorax*

These species nest in living or dead trees, decaying wood, soil, or stumps. Because of inconspicuous habits and small colonies (50 - 200 workers) they are often overlooked. Many nest by choice in preformed cavities. Nests often adjoin those of other, larger ant species, and the workers may steal food from the larger nest. Some species are inquilines (social parasites) that lack a worker caste, and others dulotic (conducting slave raids in which brood, and especially pupae, are removed to the home nest).

**\*L. acervorum** (Fabricius): Reported from the Yukon by Francoeur (1997).

**\*L. faberi** Buschinger: An obligate social parasite of the "*L. muscorum* group" *sensu lato*. Queens are more likely to be found than workers, and they can be differentiated from their hosts by larger size, darker colour, and the presence of a post-petiolar ventral spine. Described from Jasper National Park in Alberta (Buschinger 1981). Francoeur (1997) reported a *Leptothorax.* sp. nr. *faberi* from the Yukon.

**L. muscorum** (Nylander): This name has been applied to what is a complex of species, including the most northern new world ants. By comparing chromosomes numbers, Loiselle *et al.* (1990) determined that the complex includes at least four species in North America. They are found mostly in woodlands where they nest in decaying stumps, logs, or under logs or rocks. Small ants, mostly dark reddish-brown in color. Head and alitrunk are dull, and the gaster strongly shining. Distribution extends from Arizona through to Alaska and the North West Territories, and throughout northern Europe. Some authorities, e.g. Creighton (1950), consider *L. muscorum* to be solely an old world species, and refer to our species (complex) as *L. canadensis* Provancher.
**Localities**: Victoria (Blacker 1992); Cordova Bay; Vancouver; North Vancouver (WM); Hope (RBCM); Osoyoos (between 800 and 1500 m elevation) (Blades and Maier 1996); 94 Mile House (RBCM); Chilcotin region (Buckell 1932); Westwood Lake (Cariboo region; UBC); Lens Mountain (RBCM). Also reported from Montana (Wheeler and Wheeler 1988).

**L. nevadensis** Wheeler: Blackish, 2.5 mm workers, bearing 12 segmented antennae with dark coloured clubs.
**Localities**: Victoria (Blacker 1992); Osoyoos (from valley bottom to 1850 m elevation) (Blades

and Maier 1996); Oliver (WBP); Balfour (WBP); Waneta - nests found in mixed open forest and dry benchland, one tunnelled under the bark of a decayed stump (WM). Also reported from Montana (Wheeler and Wheeler 1988).

*L. nitens* Emery: Found under rocks and in duff. Small, pale yellow ants.
**Localities**: Osoyoos (below 800 m elevation) (Blades and Maier 1996); Washington (Smith 1979); and Idaho (Yensen *et al.* 1977).

*\*L. retractus* Francoeur: Nests in dead wood in forested habitats. Found in the Yukon (Francoeur 1997).

*L. rugatulus* Emery: Nests in dry, grassy sites, under wood, stones, in decaying wood, or under grass clumps. Small (2.5-3 mm), with dull head and alitrunk, gaster strongly shining. Solidly built, with a box-shaped alitrunk.
**Localities**: Victoria (Blacker 1992); Vernon (UBC); Lillooet (WM); Osoyoos (below 1500 m elevation)(Blades and Maier 1996); Westbank - in soil under a log; Summerland - in open forest in a ponderosa pine cone embedded in the soil (WM); Cache Creek (RBCM); Balfour (WBP); Waneta (WM). Also reported from Montana (Wheeler and Wheeler 1988).

## Formicoxenus

This genus was revised by Francoeur *et al.* (1985) and includes several species that were previously included in the genus *Leptothorax*. The ants of this genus are characterized by a xenobiotic lifecycle and the production of several types of functional queens including winged individuals with fully developed alitrunks (gynomorphs), wingless individuals without wing-associated thoracic structures (ergatomorphs), most of which act as workers, and intermorphs, which are intermediate in morphology.

*\*F. diversipilosus* (Smith): A guest ant in the nests of *Formica obscuripes, F. ravida*, and *F. integroides*. Reported from Washington (Alpert and Akre 1973), and Idaho (Yensen *et al.* 1977).

**F. quebecensis** Francoeur: A guest in colonies of *Myrmica alaskaensis*. Distinct from other members of the genus in having both winged and non-winged males.
**Localities**: Overlander Falls (along the upper Fraser River), and reported from several sites near Jasper, Alberta (Buschinger *et al.* 1994).

*\*F. provancheri* (Emery): A guest ant of *Myrmica incompleta*. Might be found, together with its host, in many locations in the province. Reported from Alberta (Francoeur *et al.* 1985) and Montana (Wheeler and Wheeler 1988).

## Doronomyrmex

This genus contains species that are obligate social parasites, i.e., they produce few or no workers and reproduce when a queen usurps the colony of another species.

*\*D. pocahontas* Buschinger: An obligate social parasite of a small member of the *Leptothorax muscorum* complex. Described from Jasper National Park, Alberta by Buschinger (1979).

## Tetramorium

This genus contains some important household pests.

*__T. caespitum__* (Linnaeus): This species may be of European origin.  It builds colonies under stones, near building foundations, and commonly infests houses where the omnivorous workers seem to show a preference for meat or grease.  Workers are small, and dark reddish or brownish-black, although they appear black in the field. Found in Washington (Smith 1979) and probably occurs in towns in BC.

## Dolichoderinae
These are mostly small, drab coloured ants.  They are characterized by a single segmented pedicel, no constriction between the first and second gastric segments, and a slit-like cloacal orifice.  The pupae are naked.

### *Tapinoma*
Workers commonly attend honeydew secretors such as aphids.  They also emit a substance that smells like butyric acid.

*__T. sessile__* (Say): An adaptable species that may nest in the soil beneath objects or infest houses.  Nests may contain thousands of individuals.  Workers are 2.5 - 3 mm long and yellow-brown to blackish in colour.
**Localities**: Victoria (WM; Blacker 1992); Cordova Bay (WM); Courtenay (UBC); Mesachie Lake (WM, RBCM); Mission (RBCM); Osoyoos (from valley bottom to 1850 m elevation, Blades and Maier 1996; also WBP); Oliver (WM, WBP); Penticton; Kamloops (Buckell 1932); Lillooet (Buckell, 1932; WM), Vernon (UBC); Sicamous; Westbank; Savona; Anarchist Mountain (WM); Cache Creek (RBCM); Balfour (WBP); Columbia Lake (WM); Flathead (WBP); Chilcotin region (Buckell 1932). Also reported from the Yukon (Francoeur 1997) and Montana (Wheeler and Wheeler 1988).

### *Liometopum*
These ants nest in the soil beneath cover, or under bark or in tree crevices.  The nests, which are sub-divided by paper-like material, are often difficult to find.  The workers commonly forage in single file, and many attend honeydew secretors.  They are pugnacious and eject a substance that smells like butyric acid when threatened.

**\*\****L. apiculatum*** Mayr: Workers are small to medium-sized and dark reddish-brown.  Reported by Buckell (1932) from Naramata, however, Smith (1979) described this species as occurring in the U.S. southwest and Mexico, in foothills at elevations of 1,000 - 2,000 m.

## Formicinae
This subfamily is the predominant group in North America.  They are especially common in BC.  They lack a sting but are able to eject formic acid when disturbed.

### *Brachymyrmex*
These ants usually build small colonies in the soil, under objects.  They attend honeydew-secreting insects.

*__B. depilis__* Emery: Nests are in the soil under some object.  Workers are minute (1.5-2 mm), pale brown, slow-moving, and inconspicuous.  They feed chiefly on honeydew secreted by aphids and mealy bugs on the roots of plants, and spend almost all of their time underground.
**Localities**: Victoria (Blacker 1992); Vancouver (UBC); Lillooet (CNC); Westbank; Anarchist Mountain; Trail; Waneta (WM); Balfour (WBP).

### Camponotus

These are called the carpenter ants because of their preference for making nests in wood. They do however, also nest in the soil, and under or in hollow twigs or branches. Workers are highly polymorphic and can become aggressive and bite in defense of a nest.

*C. essigi-hyatti* complex: Small colonies with several dozen to a few hundred workers. Workers are smooth and shining and vary in size from small to large. Specimens collected by G. L. Ayre in Osoyoos in 1972 were determined at the time by R. Snelling to belong to the *essigi-hyatti* complex. These specimens key out to *C.* cf. *hyatti* Emery using the keys of Snelling (1988) and Wheeler and Wheeler (1986). They may be a new species in this complex.
**Localities**: Osoyoos, under the bark of sage brush, *Artemesia tridentata*. (WM).

*C. herculeanus* (Linnaeus): Large colonies can be found in rotting logs and stumps, especially of conifers. A common structural pest. The head and gaster of the major workers are black and the alitrunk black anteriorly and red posteriorly. Head and alitrunk moderately shining, the gaster dull. Workers are large to very large.
**Localities**: Mesachie Lake (WM); Princeton (UBC); Cache Creek (RBCM); Clinton; Lillooet (WM); Douglas Lake, Revelstoke, Invermere (Buckell 1932); Arrow Lake (Buckell 1927); Chilcotin and Cariboo regions (Buckell 1932); Blue River (WBP). Also reported from the Yukon (Francoeur 1997); Alaska (Nielsen 1987); the North West Territories (Brown 1949); Alberta (Sharplin 1966), Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988). This species no doubt occurs in northern BC as well.

*C. laevigatus* (Smith): Has habits similar to *C. herculeanus* and is also occasionally found in buildings. Buckell (1927) reported that this species was not common, and could usually be taken from fir logs at higher elevations. Workers are large to very large, and entirely black and shining, often with bluish reflections.
**Localities**: Thetis Island (Blacker 1992); Cordova Bay (RBCM); Nanaimo; Osoyoos (between 800 to 1500 m elevation, Blades and Maier 1996; WBP); Westbank (WBP); Lillooet (WM); Cranbrook (Buckell 1932); Lens Creek (RBCM). Also reported from Montana (Wheeler and Wheeler 1988).

*C. modoc* Wheeler: Some consider this a subspecies of *C. herculeanus*. Workers are medium-sized to very large, black with golden yellow setae and pubescence on the gaster. The head is feebly shining to dull, and the alitrunk and gaster dull. Nests of several hundred to 1000 workers are usually found under or in wood, and workers may be seen climbing trees, possibly to take honey dew from aphids.
**Localities**: Victoria; Thetis Island (Blacker 1992); Brentwood Bay (WM); Mesachie Lake (RBCM); Qualicum Beach (WBP); North Vancouver (WM); Port Coquitlam (WBP); Vancouver; Armstrong (KN); Oliver (WBP); Summerland; Greenwood; Clinton; Lens Creek; Lytton (RBCM); Columbia Lake; Fruitvale, (WM); Balfour; Flathead (WBP); Chilcotin region (Buckell 1932); Lac la Hache (RBCM). Also reported from Montana (Wheeler and Wheeler 1988).

*C. nearcticus* Emery: Constructs small nests in dead twigs and branches, under the bark of live or dead trees, in galls, pine cones, rotting logs, stumps, fence posts, or roofing. Medium-sized to very large.
**Localities**: Osoyoos (below 800 m elevation) (Blades and Maier 1996); Balfour (in house; (WBP). Also listed from Alberta (Sharplin 1966) and Idaho (Yensen *et al.* 1977).

***C. noveboracensis*** (Fitch):  This may, like *C. modoc*, also be a subspecies of *C. herculeanus*, and is also an occasional house pest. Workers are dull, varying to head and alitrunk dull with a moderately shining gaster.  The head is black to reddish black, alitrunk red, and gaster black, and the size large to very large.
**Localities**: Mesachie Lake (RBCM); Port Coquitlam (WBP); Oliver (WBP; Buckell 1932); Keremeos, (Buckell 1932); Lillooet (WM); Lytton; Lens Creek, (RBCM); Chilcotin region (Buckell 1932).  Also in Alberta (Sharplin 1966) and Idaho (Yensen *et al.* 1977).

***\*C. semitestaceus*** Emery:  Nests under stones, or in soil surmounted by low craters. Workers are large to very large; the largest workers have a reddish head, pale yellow alitrunk and anterior of the gaster with the remainder of the gaster brown. Found in Washington (Smith 1979).

***C. vicinus*** Mayr:  Nests in soil under stones, or rotting wood buried in the soil.  The head and gaster are black, and the alitrunk and legs red, although some small workers may appear entirely black in the field.  Large to very large.  May be largely nocturnal (Blacker 1992).
**Localities**: Victoria; Thetis Island (Blacker, 1992);  Mesachie Lake (RBCM); Galiano Island; Vancouver (UBC); Coquitlam (WBP); Osoyoos (below 1500 m elevation, Blades and Maier 1996; WBP); Oliver (WBP); Rock Creek; Vernon; Kamloops; Nicola Lake; Lillooet; (Buckell 1932); Westbank (WBP; WM); Anarchist Mountain; Oliver; Kalamalka Lake (WM); Lytton; Lens Creek; Robertson Valley; Clinton (RBCM); Summerland; Penticton (WM); Balfour (WBP); Waneta (WM); Chilcotin region (Buckell 1932). Also reported from Montana (Wheeler and Wheeler 1988).

### *Lasius*

Members of this group build nests in exposed soil, under objects, or in rotting wood.  The colonies are small to medium-sized, and the workers may attend or foster honeydew-excreting insects.  Many of the species found here have a holarctic distribution.

***L. alienus*** (Foerster):  Prefers well or partially shaded woodlands, although occasionally found in open areas.  Nests are found under rotting logs or rocks, and may contain several thousand workers.  May invade houses.  Workers are small (2.3-3 mm), dull, and dark reddish-brown.
**Localities**: Victoria (Wilson 1955); Mesachie Lake (RBCM); Cordova Bay; North Vancouver (WM); Vancouver (UBC; WBP); Queen Charlotte Islands (UBC); Hope (RBCM); Manning Park (Wilson 1955); Yale (WM); Osoyoos (WM); Oliver (WBP); Okanagan Falls (Buckell 1932); Westbank (WM); Lillooet (Wilson 1955); Monashee Mountains; Emerald Lake (near Field) (Wilson 1955); Slocan (UBC); Fruitvale; Waneta, (WM); 70 Mile House (RBCM); Blue River (WBP). Also reported from Montana (Wheeler and Wheeler 1988).

***L. crypticus*** Wilson*:* Nests under stones or builds crater nests in open areas. Workers are small and reddish-brown.
**Localities**: Osoyoos (below 1500 m elevation; Blades and Maier, 1996); Oliver (WBP); Westbank; Greenwood; Savona; Columbia Lake (WM). Also reported from Montana (Wheeler and Wheeler 1988).

***L. fallax*** Wilson:  Nests under stones in forest clearings. Workers are small and brown.
**Localities***:*  Osoyoos (between 800 and 1500 m elevation) (Blades and Maier 1996). Also reported from Montana (Wheeler and Wheeler 1988).

***L. flavus*** (Fabricius):  Subterranean. Nests mostly under stones.  May attend aphids that feed on the roots of grasses.  Workers are moderately shining, small, with a brown head and reddish-

yellow alitrunk and gaster.

**Localities**: Westbank (WM); Osoyoos; Chilcotin region (Buckell 1932). Listed from Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

*L. neoniger* Emery: Builds nests with a sandy crater or nests under stones in open areas. The distribution of this species may be influenced by a tendency to nest along roadsides. The small, dark reddish-brown workers tend honeydew-secreting insects.

**Localities**: Osoyoos (below 800 m elevation)(Blades and Maier 1996); Oliver (WBP); Armstrong (WM). Reported from Alberta (1966); the Yukon (Francoeur 1997); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

*\*L. niger* (Linnaeus): nests under stones in both forest and open situations. Found in Washington (Smith 1979) and Idaho (Yensen *et al.* 1977). Wheeler and Wheeler (1986) consider that this is in fact *L. alienus*.

*L. pallitarsis* (Provancher): Usually nests in forested areas, in rotting logs and stumps, or under stones, but is sometimes abundant in grasslands. Eats a variety of foods and is sometimes associated with aphids and coccids. An occasional house pest. Workers are approximately 3.5 mm long and brown. The head is shining, the alitrunk and gaster moderately shining. Distributed throughout all of southern BC, and in the north, west of the Rocky Mountains.

**Localities**: Victoria (Wilson 1955); Mesachie Lake (RBCM); Brentwood Bay; Cordova Bay (WM); Alert Bay (Wilson 1955); Galiano Island (UBC); Vancouver (WBP; WM; UBC); North Vancouver; Deep Cove (WM); Chilliwack (Wilson 1955); Yale (WM); Osoyoos (between 800 and 1500 m elevation) (Blades and Maier 1996); Terrace (Wilson 1955); Sicamous (WM); Salmon Arm (Buckell 1932); Penticton; Chase; Glacier; Howser (Selkirk Mtns)(Wilson 1955); Balfour (WBP); Fruitvale; Kinnaird (WM); Creston (WBP); 100 Mile House; 70 Mile House; Lac La Hache, (RBCM); Tete Jaune Cache (WBP). Reported from Alaska (as *L. sitkaensis;* Nielsen 1987). Also reported from Montana (Wheeler and Wheeler 1988).

*L. subumbratus* Viereck: A temporary social parasite of *L. pallitarsis*. It nests under stones or rotting logs. Workers are small and concolorous reddish-yellow. The head and gaster are shining and the alitrunk moderately shining.

**Localities**: Keremeos (Buckell 1932). Listed from Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

*\*L. umbratus* (Nylander): Is reported from Alberta (Sharplin 1966); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988). Workers are small with shiny, yellowish-red head and gaster and a dull, reddish-yellow alitrunk.

*L. vestitus* Wheeler: Small yellowish-brown, strongly shining ants. The entire body of the workers is covered with long, mostly erect, silky yellow setae. So much so, in fact, that the gaster has the appearance of a brush in side view. Said to be concentrated along the Pacific coast (Wilson 1955) but in the U.S. found inland as far as Idaho (Yensen *et al.* 1977) and Nevada (Wheeler and Wheeler 1986).

**Localities**: Nanaimo; Forbidden Plateau (Vancouver Island)(Wilson 1955).

### Acanthomyops

Most members of this genus nest in the soil, usually beneath objects, but they are also found nesting in rotting logs and stumps, under basements, or around the foundations of buildings. They are mostly subterranean, and some foster honeydew secretors. The queens and workers have a

citronella or lemon-verbena odor, and the winged queens are often mistaken for termites. Most, or all are temporary social parasites of *Lasius* species. The workers are relatively slow moving and run about when disturbed. They are small (<4 mm), yellow to yellowish-brown, and shining. Their food is mainly honeydew from aphids or coccids.

***A. coloradensis*** Wheeler: Nests mostly under stones. Small, strongly shining ants with a brownish-yellow head and gaster and a yellow alitrunk.
**Localities**: 70 Mile House (RBCM). Also found in Alberta and south to New Mexico (Smith, 1979), including Montana (Wheeler and Wheeler 1988).

***A. interjectus*** Mayr: Found in woodlands, pastures, and meadows, under objects, near foundations, or in the open with a small mound.
**Localities**: Kamloops (Buckell 1932). Listed from Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

***A. latipes*** (Walsh): Nests are found in open woodlands, meadows, or pastures, in exposed soil with a mound, or at the base of stumps. The workers are small and shining, with brown head, brownish-yellow alitrunk, and brown to brownish-yellow gaster. They are distributed coast to coast in southern Canada.
**Localities**: Vancouver (KN); Lillooet (CNC); Kamloops (Buckell 1932); Keremeos (UBC). Also reported from Montana (Wheeler and Wheeler 1988).

***A. occidentalis*** (Wheeler): Nests under stones in dry sandy soil. Workers are small and yellowish-brown in colour.
**Localities**: Westbank (WM). Also reported from Montana (Wheeler and Wheeler 1988).

****A. claviger*** (Roger): Reported by Buckell (1932) from Penticton; Minnie Lake and the Chilcotin region, but considered by Smith (1979) to be a species of eastern North America.

### *Myrmecocystus*
The species of this genus are mostly predator-scavengers but they also collect honeydew, and unusually, the carbohydrate rich secretions of plants. They are associated with arid climates and are best known for the presence of individuals known as repletes. Repletes act as living storage jars for honeydew or nectar; their gasters can swell to the size of a pea. They hang suspended from a gallery ceiling until their stores are required by the colony.

***M. testaceus*** Emery: This nocturnal species forms nests in well drained, stony or sandy soils. Workers are medium-sized and shining, with yellow head and alitrunk, brownish-yellow gaster, and large, black eyes.
**Localities**: Osoyoos (below 800 m elevation) (Blades and Maier 1996).

### *Formica*
This is the largest genus of ants north of Mexico. Although most species are predators and scavengers and will collect honeydew, they show a great diversity of habits and can be subdivided into several species groups. They are mostly medium-sized to large ants, with the workers commonly 4 - 8 mm long, although some species may be smaller. They release formic acid as a defensive compound.

***Neogagates*** group. These ants form small colonies (to several hundred individuals) in soil, frequently under objects. They are the smallest ants in the genus *Formica* and are commonly

enslaved by members of the *microgyna* and *sanguinea* species groups. All workers have a shining surface.

***F. lasioides*** Emery: Commonly found in grasslands under stones or in nests with exposed entrances or small craters. The workers are small to medium-sized and the colour can be variable but the head and gaster are usually reddish-black and the alitrunk dusky red or yellowish-red. There are a few erect setae on the antennal scapes. Shining to strongly shining. They are distributed coast to coast in southern Canada and north into Alaska.
**Localities**: Hope (RBCM); Kamloops; Vernon; Nicola (UBC); Osoyoos (above 800 m elevation)(Blades and Maier 1996); Lillooet; Anarchist Mountain; Summerland; Edgewood (WM); Lens Mountain (RBCM); Chilcotin region (Buckell 1932). Reported from Alberta (Sharplin 1966); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

***F. manni*** Wheeler: Nests under stones in gravelly or sandy soil, usually in arid areas. Head and alitrunk reddish-yellow and gaster reddish-black varying to head and alitrunk reddish-brown, gaster black. Small to medium-sized and shining. Workers are fast and timid, although large colonies may be aggressive.
**Localities**: Lac du Bois (near Kamloops), (UBC). Listed from Idaho (Yensen *et al.* 1977).

***F. neogagates*** Emery: Nests in woodlands, under various covering objects, and often forming a mound of soil. Head and gaster dusky red and alitrunk dark reddish brown varying to head dark red dorsally and brown ventrally, alitrunk reddish-yellow with brown markings, and gaster dark reddish brown. Small to medium-sized and strongly shining.
**Localities**: Osoyoos (below 800 m elevation)(Blades and Maier 1996), (Buckell 1932; UBC); Oliver (Buckell 1932; UBC); Greenwood (WM); Westbank (WM; CNC); Cache Creek (RBCM); Chilcotin region (Buckell 1932). Also reported from Montana (Wheeler and Wheeler 1988).

***F. vinculans*** Emery: Considered by some to be a subspecies of *F. neogagates*. Nests in open, sunny, prairie-like locations utilizing some vegetative debris. When nests are disturbed, the workers display aggressive alarm. Alitrunk paler than head and gaster.
**Localities**: Osoyoos (Maier and Blades 1996).

***F. bradleyi**** Wheeler: This species occurs in sandy regions. The workers are small to medium-sized and yellowish red. Reported from Alberta (Sharplin 1966); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

***Fusca*** group. Nests are in the soil and are usually started under a protecting object. The nest entrance is surrounded by a low mound or irregular crater of soil. Members of this group are commonly used by slave-making *Formica* species. The workers are generally fast and timid, but actively defend large colonies. This group is discussed in detail by Francoeur (1973).

***F. accreta*** Francoeur: Relatively docile ants, black, and 4-7 mm long. Nests may contain over 1000 workers, are found in the soil, and are usually started under a rock or object. Blacker (1992) reported this to be the most conspicuous ant in Victoria.
**Localities**: Thetis Island (Blacker 1992); Victoria; Sidney; James Island (near Saanich); New Westminster; Kootenay Lake (Francoeur 1973). Also reported from Washington; Idaho and Montana (Francoeur 1973).

***F. aerata*** Francoeur: Nests under rocks in sandy soil. Workers are small, brown-coloured with a silky lustre due to pubescence. Francoeur (1973) reported this species from California, Nevada,

and Oregon. To our knowledge this is the first report of this species in Canada.
**Localities**: Kalamalka Lake (WM); Oliver; Balfour (WBP).

*F. argentea* Wheeler: Nests in open or semi-open areas; usually in sandy soil, under a rock or with a low mound. Very active ants, they ocassionally infest houses. Workers are small to medium-sized, and brownish-black with a silvery luster given by the pubescence. This species occurs coast to coast in North America.
**Localities**: Cordova Bay (WM); Victoria; Hope (Francoeur 1973); Osoyoos (from valley bottom to 1850 m elevation) (Blades and Maier 1996); Lytton (RBCM); Lillooet (Buckell 1932); Princeton (UBC); Vernon; Kelowna; Penticton; Kaslo; Creston; Cranbrook (Francoeur 1973); Trail; Waneta (WM). Also reported from Montana (Wheeler and Wheeler 1988).

*F. fusca* Linnaeus: Nests in a wide variety of situations. Workers small to medium-sized. Head dusky red, alitrunk and gaster dark reddish-brown varying to concolorous black with pale appendages. Shining, especially the head and gaster. Found from Arizona to the Yukon and east to Newfoundland, and probably throughout much of BC.
**Localities**: Patricia Bay; North Vancouver (WM); Terrace (Francoeur 1973); Manning Park (UBC); Osoyoos; Kaleden (Buckell 1932); Vernon, (UBC); Westbank; Anarchist Mountain (WM); Lillooet (WM, CNC); Merritt; Kaslo; Selkirk Mountains (Francoeur 1973); Flathead (WBP); Lac La Hache (RBCM); Chilcotin and Cariboo regions (Buckell 1932). Also reported from Montana (Wheeler and Wheeler 1988).

*\*F. gagatoides* Ruzky: An apparently holarctic species that resembles *F. neorufibarbis*. Found in northern Scandinavia and Siberia and reported from the Yukon by Francoeur (1997).

*F. hewitti* Wheeler: Nests under rocks, in rotting logs in open or in semi-open, late-succession boreal forests. Medium-sized and dark brown to reddish-black. Head and alitrunk feebly shining, gaster shining.
**Localities**: Oliver (WBP); Loon Lake (near Kamloops)(Francoeur 1973); Emerald Lake (near Field) (Buckell 1927; 1932). Listed from Alberta (Sharplin 1966); the Yukon (Francoeur 1997); Idaho (Yensen *et al.* 1977) and Montana (Francoeur 1973; Wheeler and Wheeler 1988).

*F. montana* Emery: A prairie species that builds earthen mounds, sometimes incorporating thatch or covered with grass.
**Localities:** Trail (CNC, WM); Alberta (Sharplin 1966) and Montana (Wheeler and Wheeler 1988).

*F. neoclara* Emery: Usually found in sandy soils in grasslands or open woods; sometimes at the base of plants, and sometimes in low, loose mounds of vegetation and excavated soil with many entrances. Adapts easily to man-made environments. Often forms populous colonies. Workers 3-4 mm long with blackish gaster, red-brown alitrunk and head red ventrally and reddish-black dorsally.
**Localities**: Mesachie Lake (RBCM); North Vancouver (WM); Chilliwack; Oliver, (Buckell 1927, 1932); Alexandria (UBC); Penticton; Okanagan Falls; Vernon (Francoeur 1973); Lower Nicola; Westbank; Osoyoos; Malakwa; Tete Jaune Cache, (WBP); Field; Golden, (Francoeur 1973); Columbia Lake, (WM); Lac La Hache, (RBCM); Clinton; Chilcotin region (UBC); Hazelton (Francoeur 1973). Reported from the Yukon (Francoeur 1997); North West Territories; Washington; Idaho and Montana (Francoeur 1973). Wheeler and Wheeler (1988) also list this species from Montana. Probably also in northern BC.

*F. neorufibarbis* Emery: A dominant ant in the boreal and alpine forests of North America; usually nests in rotting wood, and occasionally under stones, or in decaying sphagnum moss. The small to medium-sized workers are timid, and show a black head and gaster and red alitrunk.
**Localities**: Victoria (Blacker 1992); Vancouver Island; Vancouver (Francoeur 1973); Stave Lake; Manning Park (UBC); Port Coquitlam (WBP); Similkameen district (UBC); Merritt (Francoeur 1973); Lower Nicola (WBP); Osoyoos (between 800 and 1500 m; Blades and Maier 1996; Buckell 1927, 1932); Kelowna; Kaslo; Invermere (Buckell 1927, 1932); Kaslo; Mount Revelstoke; Carbonate (East Kootenay); Field (Francoeur 1973); Flathead (WBP); Tete Jaune Cache (WBP); Barkerville; Chilcotin region (Buckell 1927, 1932); Terrace; Queen Charlotte Islands; Liard Hot Springs (Alaska Highway) (Francoeur 1973). Also reported from the Yukon (Francoeur 1997) and Montana (Wheeler and Wheeler 1988).

*F. pacifica* Francoeur: The workers are small to medium-sized and have a fine, dense, bronze pubescence on the alitrunk, and a dark head and gaster. In Victoria, they are often found between cracks in concrete (Blacker 1992).
**Localities**: Clayoquot Sound (UBC); Rosedale (Francoeur 1973); Port Coquitlam (WBP); Washington (Francoeur 1973); Idaho (Yensen *et al.* 1977).

*F. podzolica* Francoeur: Forms populous, polygynous, crater-like or mound-like nests in boreal and alpine forests, commonly in sandy soil on beaches or shores. Rarely, organic matter is incorporated into the nest. May collect some seeds. Workers are black to blackish-brown, medium-sized to large, shy, and are found from coast to coast in North America, and as far north as the North West Territories and Alaska. Wheeler and Wheeler (1988) consider that this species is *F. subsericea* Say, although they are treated as separate species by Francoeur (1973). In our key, we treat them as a single species.
**Localities**: Nanaimo; Cordova Bay (WM); Vancouver (UBC); Agassiz (Francoeur 1973); Lytton (UBC); Jackass Mountain (WM); Cache Creek (RBCM); Osoyoos (above 800 m elevation) (Blades and Maier 1996); Westbank (WM, WBP); Oliver; Jesmond; Loon Lake (near Kamloops); Lower Nicola (WBP); Kaslo; Fort Steele; Field; Golden; Cranbrook (Francoeur 1973); Balfour (WBP); Lac la Hache (RBCM); Prince George (UBC); Terrace; Rolla (Francoeur 1973). Listed from the Yukon by Francoeur (1997).

*F. subpolita* Mayr: Constructs crater or mound-like nests, with one to four openings, in sandy or gravelly soil in dry areas. Occasional honeydew and seed collectors. Small to medium-sized ants with strongly shining head and gaster and feebly shining alitrunk. Head yellowish-red, alitrunk brown, and gaster dusky red.
**Localities**: Victoria (Blacker 1992); Vancouver Island (Francoeur 1973); Malakwa (Buckell 1927); Osoyoos (below 1500 m elevation) (Blades and Maier 1996); Oliver; Okanagan Falls; Kamloops; Lillooet (Buckell 1932); Lytton (UBC, RBCM); Vaseux Lake; Kelowna (Francoeur 1973); Westbank (CNC; Francoeur 1973); Williams Lake (Francoeur 1973); Chilcotin Region (Buckell 1932); Alberta (Sharplin (1966); Idaho (Yensen *et al.* 1977); Washington (Francoeur 1973) and Montana (Wheeler and Wheeler 1988).

*F. transmontanis* Francoeur: Almost nothing is known about the ecology of this species.
**Localities**: Lillooet; Seton Lake (Francoeur 1973); Malakwa (WBP); Tete Jaune Cache; Balfour (WBP); Fort Steele; Terrace (Francoeur 1973); Jack Ass Mountain (WM); Lens Mountain (RBCM).

**F. xerophila** Smith. Nests are founded under stones or wood and sometimes show craters or messy piles of excavated soil. The medium-sized workers have a dusky red gaster, brown to

reddish-yellow alitrunk, and a head that is reddish-yellow ventrally and dark reddish-brown dorsally. Francoeur (1973) reported this species from four states: Arizona, Utah, California, and Washington and stated that it appears to prefer arid environments. To our knowledge this is the first report of its occurrence in Canada.

**Localities**: Oliver; Osoyoos; Penticton (WBP).

*Exsecta* group. These ants build conspicuous mounds in fields, woods, or at the edges of woods. Nests may be founded by budding or by queens acting as temporary social parasites.

**\*F. ulkei** Emery: Forms large mound nests, occasionally with a covering of plant debris, and located in clearings or edges of clearings in woodlands. The workers are large. Has been found at Edson and Peace River Alberta, predominantly in coniferous forests, but not in the mountains (Sharplin 1966). May be found in the Peace River region.

*Rufa* group. Nests are usually started beneath objects. Later they are marked by soil mounds or use of thatching, depending upon the species. We have followed the example of Wheeler and Wheeler (1986) by combining this and the following group (*microgyna*) in the keys, because with samples of workers only, the two groups are otherwise difficult to distinguish.

**\*F. dakotensis** Emery: Usually found in grasslands but also reported from spruce bogs. Nests in earthen mounds or under stones or grass clumps, occasionally banked with detritus. Workers are medium-sized and feebly shining. The largest workers in a colony tend to have dark red heads, yellowish-red alitrunks, and reddish-brown to black gasters. Distributed from the Maritimes to Alaska, and south to New Mexico (Smith 1979), and therefore likely to be found in at least parts of BC. Has been found in the foothills and the Peace River region of Alberta (Sharplin 1966), from the Yukon (Francoeur 1997), and Montana (Wheeler and Wheeler 1988).

**F. integroides** Emery: Nests are built under logs and stumps banked with plant debris, and may contain tens of thousand of workers. The subspecies *F. integroides integroides* is likely to be found in the coastal mountains and on the west slope of the Cascades, and the subspecies *F. integroides propinqua* on the eastern slope (Smith 1979). Wheeler and Wheeler (1986) consider these two to be separate species. Workers are 5-8 mm long and dull. Major workers have orange heads, brown alitrunks, and reddish-brown gasters. Minors are more uniformly blackish-brown.

**Localites**: North Vancouver (GLA); Nicola (Buckell 1927); Osoyoos (below 1500 m elevation) (Blades and Maier 1996); Salmon Arm (Buckell 1932); Princeton (UBC); Westbank; Summerland; Kamloops; Lillooet (WM); Lytton (RBCM); Lower Nicola (WBP). Also reported from Montana (Wheeler and Wheeler 1988).

**\*\* F. laeviceps** Creighton: Nests mostly under stones and logs, in open areas. Workers are small to large. The head is reddish, alitrunk yellow with brown markings, and the gaster black.

**Localities**: A single alate queen was found in a car at Revelstoke but may have entered the car east of the Rockies (WBP). Reported from Montana (Wheeler and Wheeler 1988).

**F. obscuripes** Forel: Nests in open areas. Nests are usually initiated at the base of a plant, while the finished nest is a large dome-shaped mound of detritus with some thatching. At higher elevations, the nests are often smaller and under a stone. The workers are active and will bite readily. This is one of the commonest ants in BC. Medium-sized to large. Head and alitrunk are yellowish to reddish-brown, and the gaster black.

**Localities**: Brentwood Bay (WM); Saltspring Island (UBC); Kaleden; Penticton; Minnie Lake

(Buckell 1932); Lillooet; Greenwood (WM); Chilcotin region (Buckell 1932); Alberta (Sharplin 1966); Idaho (Yensen *et al*. 1977), and Montana (Wheeler and Wheeler 1988).

***F. obscuriventris*** Mayr: Nests in forests under logs and stones. Moderate use of thatching. Nests include small and large workers. Smaller workers are dull but larger workers have dull heads and feebly shining alitrunks and gasters. Heads are reddish, alitrunks brown or reddish-brown, and gasters with each segment reddish brown anteriorly and black posteriorly.
**Localities**: Sicamous (WM); Oliver; Balfour (WBP); Alberta (Sharplin 1966); Idaho (Yensen *et al*. 1977) and Montana (Wheeler and Wheeler 1988).

***F. oreas*** Wheeler: Nests are found in wooded areas or grasslands, under stones or logs banked with debris. Workers range in size from small to large. Head and alitrunk are brownish, although sometimes yellowish-brown in larger workers, and the gaster dark reddish-brown to brown. Largest workers with head moderately shining, alitrunk and gaster dull. Smaller workers dull to feebly shining.
**Localities**: Oliver (Buckell 1932); Christina Lake; Kamloops (WM); Chilcotin region (Buckell 1932); Alberta (Sharplin 1966); Idaho (Yensen *et al*. 1977) and Montana (Wheeler and Wheeler 1988).

***F. ravida*** Creighton: (= *F. haemorrhoidalis* Emery) Found in areas of moderate to sparse vegetation cover. The nests are usually started under logs or stones, later incorporating moderate amounts of thatch. Workers are medium-sized to large with yellowish-red heads, reddish-yellow alitrunks, and dark reddish-brown gasters.
**Localities**: Victoria (UBC); Westbank (WM, WBP); Osoyoos (from valley bottom to 1850 m elevation) (Blades and Maier 1996; WM); Savona; Lillooet (WM); Balfour (WBP); Trail; Columbia Lake (WM); Blue River (WBP). Also reported from Montana (Wheeler and Wheeler 1988).

***F. subnitens*** Creighton: Usually nests in grasslands. Nests are under stones and banked with debris, or are dome shaped mounds of thatch and detritus. Workers are small to large. The head is yellowish-red, alitrunk brown, and gaster reddish-black.
**Localities**: Vancouver (WM); Westbank (CNC; WM); Fruitvale; Trail; Field (WM). Reported also from Washington; Alberta (Smith 1979) and Idaho (Yensen *et al*. 1977).

***Microgyna*** group. Nests are usually thatched, the thatch scattered about the nest opening so as to resemble a flattened disc. Queens are believed to be temporary social parasites of other *Formica* species. They enter host colonies, are accepted by host workers, and produce their own worker brood. Eventually the host workers die out.

***F. densiventris*** Viereck: (= *F. rasilis* Wheeler) Nests under stones or logs. The workers are small to medium-sized, dull, with reddish-brown head and alitrunk, and black gaster.
**Localities**: Westbank (GLA; WM); Lillooet (CNC); Idaho (Yensen *et al*. 1977).

***F. microgyna*** Wheeler: Nests are usually begun under stones, in meadows or open forests. Thatch may be incorporated as the nest grows. The workers are small to medium-sized, mostly brownish, and dull to feebly shining.
**Localities**: Osoyoos (above 1500 m elevation) (Blades and Maier 1996). Also reported from Montana (Wheeler and Wheeler 1988).

***F. spatulata*** Buren: Found under stones. Its host is *F. fusca*.

**Localities**: Oliver (WM). Also reported from Montana (Wheeler and Wheeler 1988).

*F. whymperi* Forel: Small nests under stones and logs, banked with plant debris. The workers are medium-sized, dull, with head and alitrunk reddish-yellow varying to dark brown, in all cases covered with dark brown infuscation, and gaster dark reddish-brown.
**Localities**: Emerald Lake (near Field)(Buckell 1927, 1932); Alaska (Nielsen 1987); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988). Probably in northern BC as well.

*Sanguinea* group. These are facultative slave makers of other *Formica* species, i.e., they often have slaves but can survive without them. They take over a nest by killing or driving off the host workers. Some also conduct slave raids.

*F. curiosa* Creighton: Workers are medium-sized to large, concolorous reddish-yellow, and dull. Their host is *Formica lasioides*. Reported by Smith (1979) as having been found in BC. Also reported from Montana (Wheeler and Wheeler 1988).

*F. obtusopilosa* Emery: Small colonies in meadows or grasslands. Workers are small to large with reddish brown to yellowish-red head and alitrunk, and black gaster. Head and gaster are feebly shining and the alitrunk is dull. Known to take *F. neogagates* slaves.
**Localities**: One stray collected at Oliver (WBP). Also reported from Montana (Wheeler and Wheeler 1988).

*\*F. puberula* Emery: Workers are medium-sized to large and feebly shining. Head dark red to yellowish-red with dark brown to yellowish-red markings, alitrunk reddish-brown to brown, gaster dark reddish-brown. Hosts are *F. altipes*, *F. bradleyi*, *F. fusca*, *F. hewitti*, *F. neorufibarbis*, *F. pallidefulva*, *F. rasilis*, and *F. subpolita*. Listed from Alberta (Sharplin 1966), Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

*\*F. subintegra* Emery: Workers are 5 - 6 mm long, with a brown gaster and reddish-yellow head, alitrunk and legs. Although Smith (1979) suggests a distribution that includes only eastern North America, this species was reported by Buckell (1927; 1932) from Vaseux Lake; and by Sharplin (1966) from Alberta.

*F. aserva* Forel: (= *F. subnuda* Emery) This ecologically versatile species will construct colonies in sunny locations in stumps or under stones, in fields, pastures, and forests. The nests may contain several hundred workers. Head and alitrunk of workers blood red, gaster black. Workers 6-8 mm long. Hosts are *F. accreta, F. altipetens*, *F. fusca, F. montana, F. neorufibarbis*, and *F. subpolita*. The range extends from Arizona through to Alaska (Smith 1979).
**Localities**: Cordova Bay; Victoria (WM); Hope (RBCM, WBP); Salmon Arm (Buckell 1932); Cache Creek (UBC); Osoyoos (above 1500 m elevation) (Blades and Maier 1996); Anarchist Mountain (WM); Balfour; Flathead (WBP); Lac La Hache (RBCM); Tete Jaune Cache (WBP). Also listed from Alaska (Nielsen 1987); Alberta (Sharplin 1966); the Yukon (Francoeur 1997); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988). Undoubtedly occurs in northern BC as well.

### *Polyergus*

The members of this genus are obligatory or true slave makers. They conduct slave raids on nests of *Formica* spp. and bring back larvae and pupae. Some of these are consumed and others allowed to eclose as adults which then tend the brood of the slave-making queen.

*P. breviceps* Emery: The workers are medium-sized to large, pubescent, and yellowish-brown, except for the tip of the gaster which is slightly darker. The head and alitrunk are dull and the gaster feebly shining. There is a sudden and strong enlargement near the distal end of the antennal scape. Potential local hosts are *F. argentea*, *F. fusca*, *F. neoclara*, *F. neorufibarbis*, *F. pallidefulva*, and *F. subpolita*.

**Localities**: Osoyoos (between 800 and 1500 m elevation) (Blades and Maier 1996); Lillooet (CNC); Westbank (WM); Chilcotin region (Buckell 1932). Also listed from Alberta (Sharplin 1966); Idaho (Yensen *et al.* 1977) and Montana (Wheeler and Wheeler 1988).

# DISCUSSION

In general, the diversity of ants in British Columbia is poor compared with more southern areas of North America even though the diversity of landforms and climatic zones is high. The relatively small number of species in this list (73 species reported from within BC) may be due in part to limited collecting and identification but it is probably also influenced by British Columbia's northern location. Table 1 illustrates the well-known decrease in ant diversity with increased latitude in the northern hemisphere. In the southern hemisphere, there is a corresponding decrease in species as the south pole is approached (Kusnezov 1957). As Table 1 shows, BC's ant diversity, as represented by this checklist, is more or less expected for our region.

There is also a decrease in species with increasing elevation (Kusnezov 1957). For example, Montana has 76 species of ants (Wheeler and Wheeler 1988) while North Dakota, with a generally lower elevation, has 86 species (Wheeler and Wheeler 1963). However, this difference may also be due, in part, to more intensive collecting in the latter state. As Table 1 shows, Montana and Idaho, both generally of the same latitude, also differ in species diversity. Idaho, with a greater ant diversity, has more areas of low elevation, extends further south, has a milder climate than states to the east of the Continental Divide (Hambridge, 1941), and southern Idaho has few geographical barriers between it and the rich ant diversity of southwest North America. It should not come as a surprise that British Columbia, with its diversity of landforms and ocean-moderated climate, has more ant species than in Manitoba, with 52 species (Wheeler *et al.* 1989).

**Table 1**

Numbers of ant species reported from areas of North America at different latitudes.

| Location | Latitude | No. Reported Species | Reference |
|---|---|---|---|
| Central Alaska | 62-66° N | 18 | Nielson (1987) |
| Yukon | 60-69° N | 18 | Francoeur (1997) |
| British Columbia | 49-60° N | 73 | This paper |
| Montana | 45-49° N | 76 | Wheeler and Wheeler (1988) |
| Idaho | 42-49° N | 115 | Yensen *et al.* (1977) |
| Nevada | 35-24° N | 176 | Wheeler and Wheeler (1986) |
| Texas | 26-37° N | 181 | Wheeler *et al.* (1989) |
| Costa Rica | 8-11° N | 329 | Wheeler *et al.* (1989) |

In this paper, we have not discussed exotic ant species temporarily established indoors. Naumann (1994) reported on two tropical species, *Wasmannia auropunctata* Roger (Myrmicinae) and *Paratrechina longicornis* Emery (Formicinae) established in a Vancouver tropical display. These species require high temperatures and humidity and are unlikely to survive outside of the exhibit.

Future collectors will undoubtedly find new native and exotic ant species in British Columbia.

The greatest numbers of species (and collectors) are likely to be found in drier and warmer areas of the south such as the Okanagan and Boundary districts. In aspects of plant life and climate, those areas represents the northern fringe of the Great Basin, an area rich in ant species, and also containing many biological transition zones. Northern British Columbia, on the other hand, has been particularly neglected with regards to collecting. Recently, Francoeur (1997) has listed the species known to occur in the Yukon, and many of them can probably be found in northern British Columbia. Small and subterranean species are also likely to be underrepresented in collections relative to those species that have larger workers, larger colonies, and active, terrestrial foragers. It is hoped therefore, that future work will add to the list of species presented here and to our knowledge of the distribution and ecology of individual species.

## ACKNOWLEDGEMENTS

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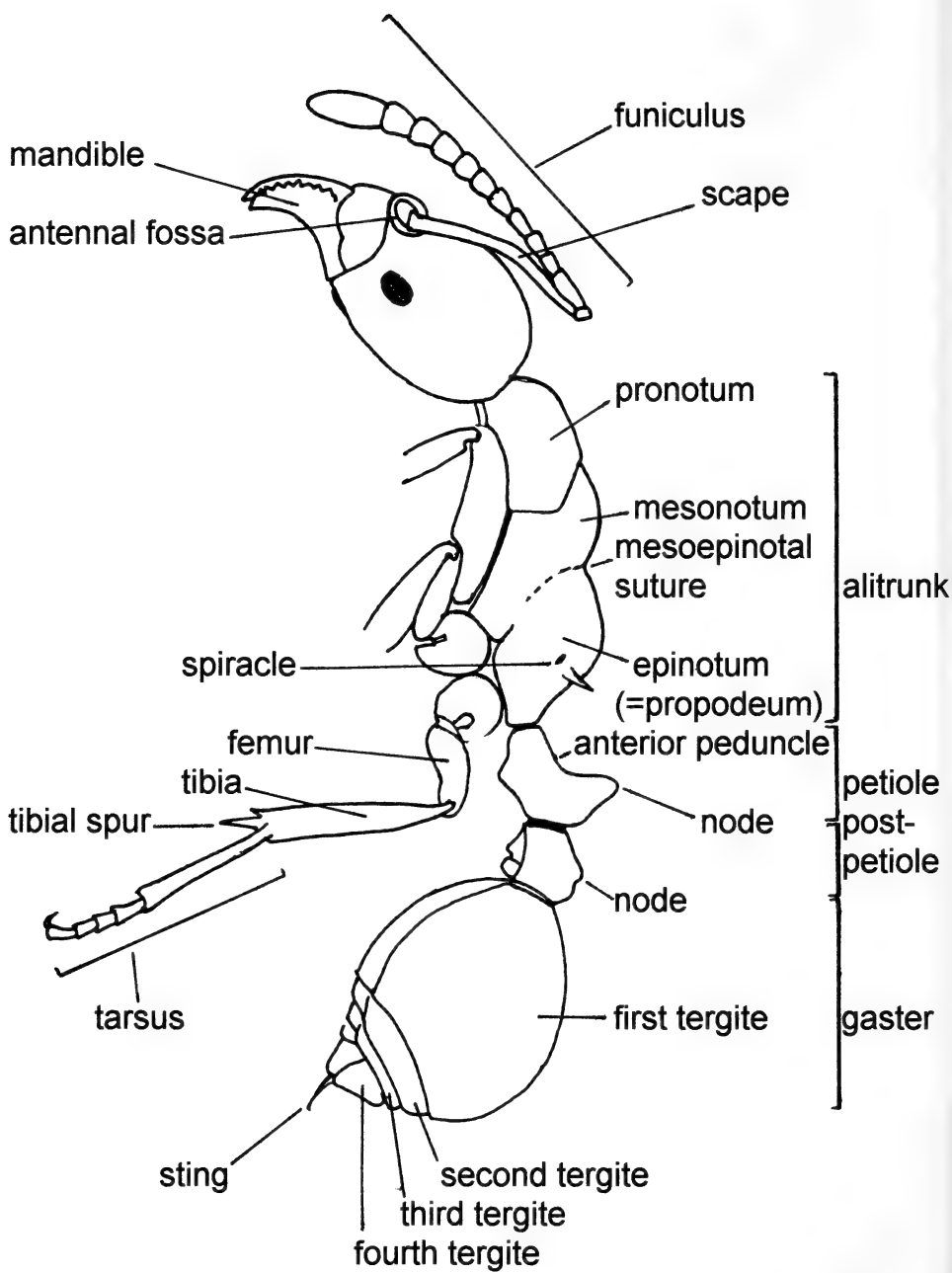
**Figure 1.** External anatomy of a typical ant showing many of the features referred to in the keys.
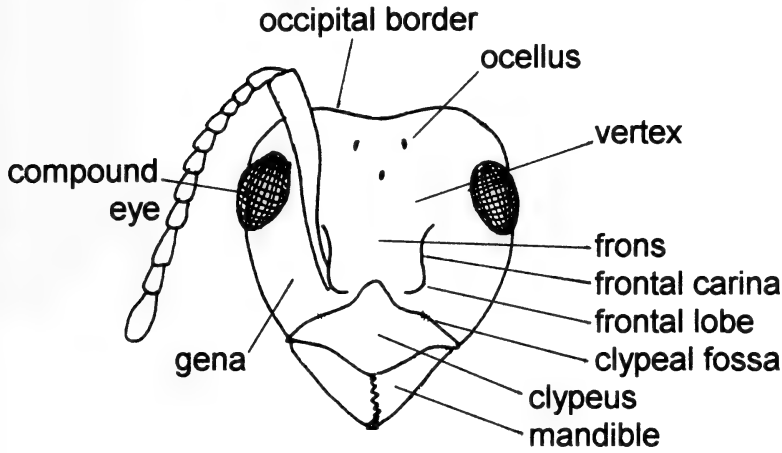
**Figure 2.** External anatomy of the head of a typical ant showing many of the features referred to in the keys.
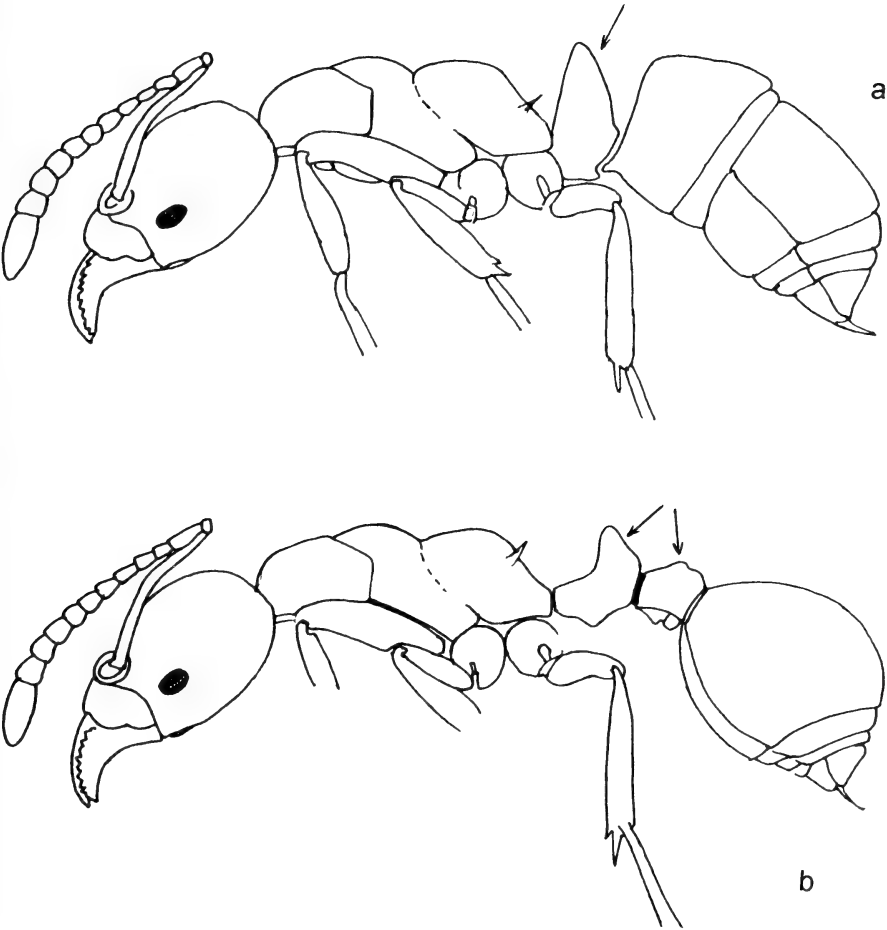


**Figure 3.** Features referred to in the Key to the Subfamilies. a) Ant with petiole; b) ant with petiole and postpetiole.
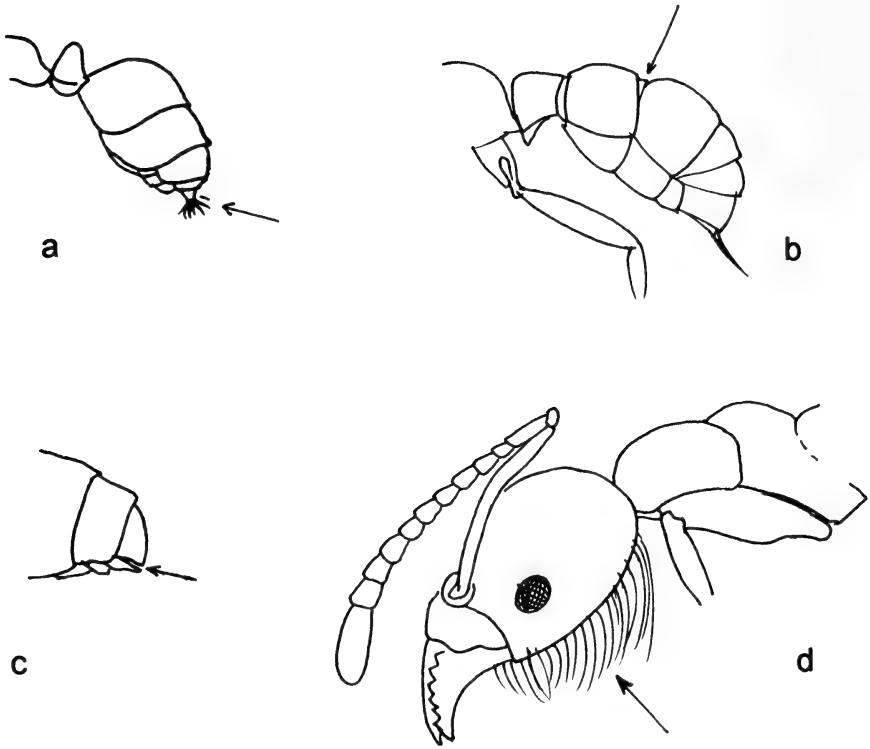
**Figure 4.** Features referred to in the Key to the Subfamilies and the Key to the Genera. a) Acidopore; b) constriction between first and second segments of gaster, typical of the Ponerinae; c) slit-like opening on gaster of Dolichoderinae; d) psammaphore.
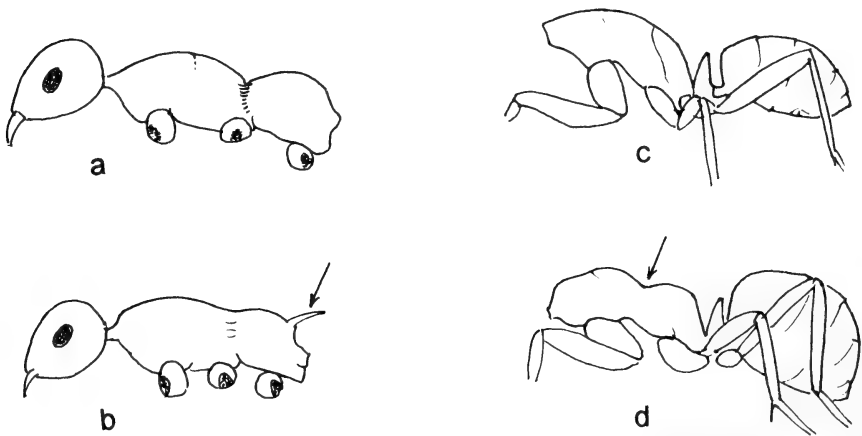


**Figure 5.** Features referred to in the Key to the Genera. a) Lateral view of propodeum lacking teeth; b) propodeum armed with teeth; c) profile of alitrunk typical of *Camponotus*; d) profile of alitrunk typical of *Formica* and *Lasius*.
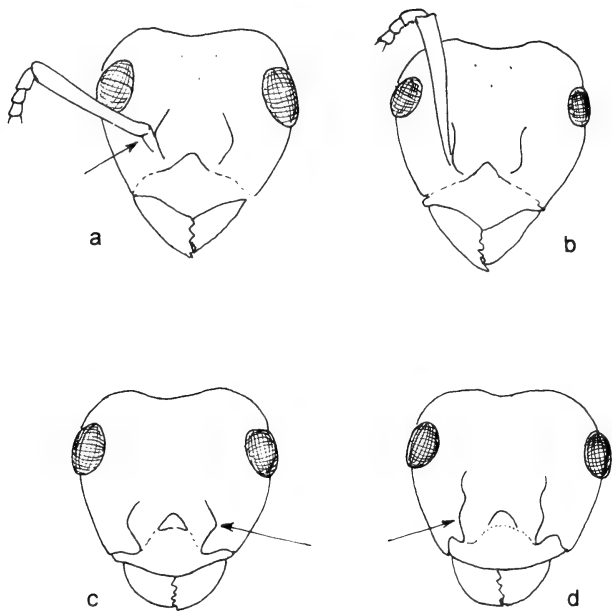
**Figure 6.** Features referred to in the Key to the Major Workers of the Species. a) Antennal scape forming a right-angled bend; b) antennal scape lacking a right angle; c) downward-deflected frontal lobes; d) rounded frontal lobes.
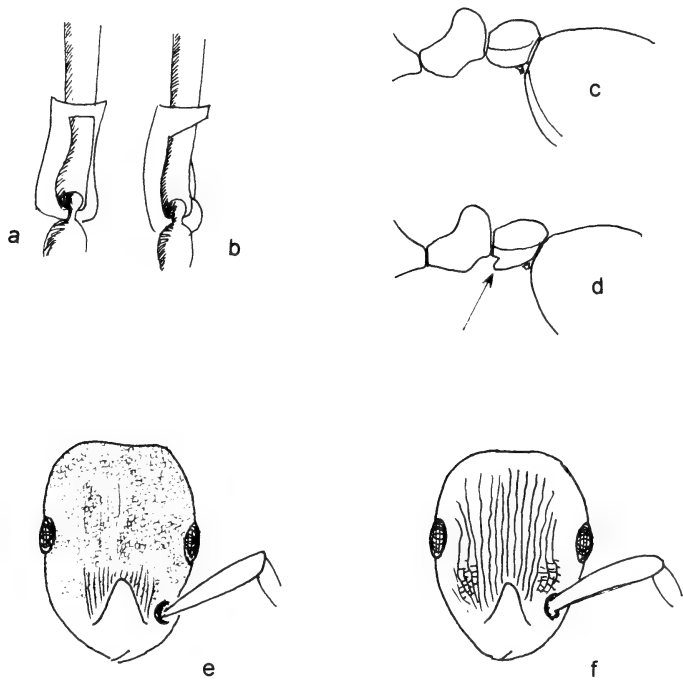
**Figure 7.** Features referred to in the Key to the Major Workers of the Species. a) Lamina on antennal scape typical of *Myrmica lobifrons*; b) antennal scape typical of *M. latifrons*; c) postpetiole showing a prominent tooth on the ventral surface; d) postpetiole lacking a ventral tooth; e) head of *Formicoxenus* female showing reticulated sculpturing; f) longitudinal lines on the head of a *Formicoxenus* female.
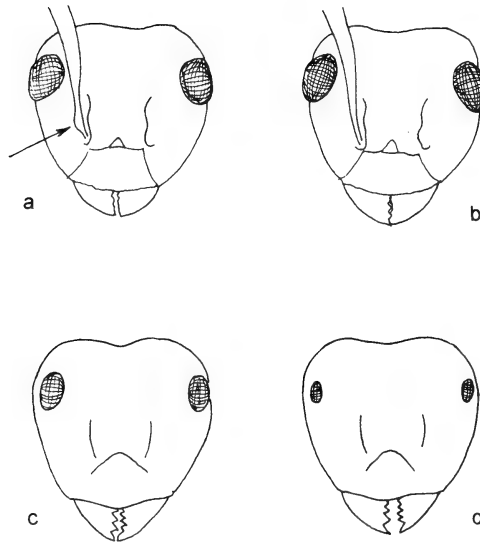
**Figure 8.** Features referred to in the Key to the Major Workers of the Species. a) Lateral lobe on antennal scape; b) antennal scape without a lobe; c) large-eyed *Lasius* species; d) small-eyed *Lasius* species.
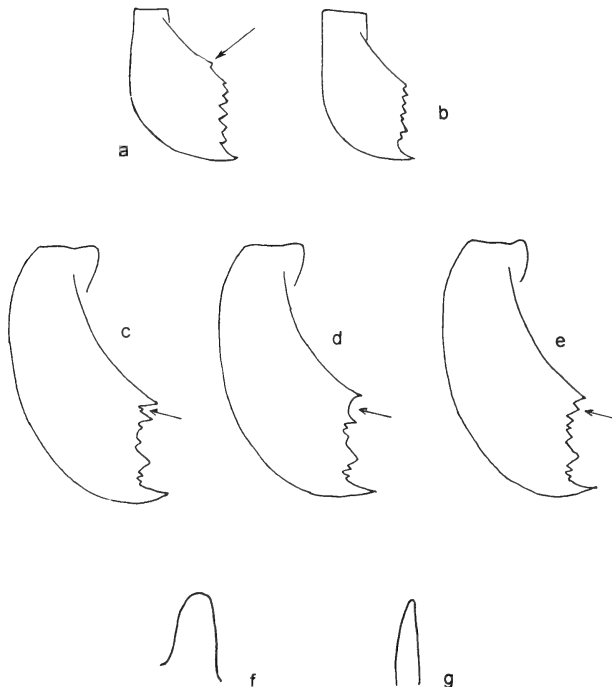


**Figure 9.** Features referred to in the Key to the Major Workers of the Species. a) Mandible with an offset tooth at the basal angle; b) mandible with basal tooth aligned with the other teeth; c) mandible with penultimate basal tooth of reduced size; d) mandible with a gap between the penultimate and basal tooth that exceeds the width of the basal tooth; e) mandible with penultimate and basal teeth of unequal size and the gap between them the same as the width of the terminal tooth; f) profile of a blunt-crested petiole; g) profile of a thin, sharp-crested petiole.
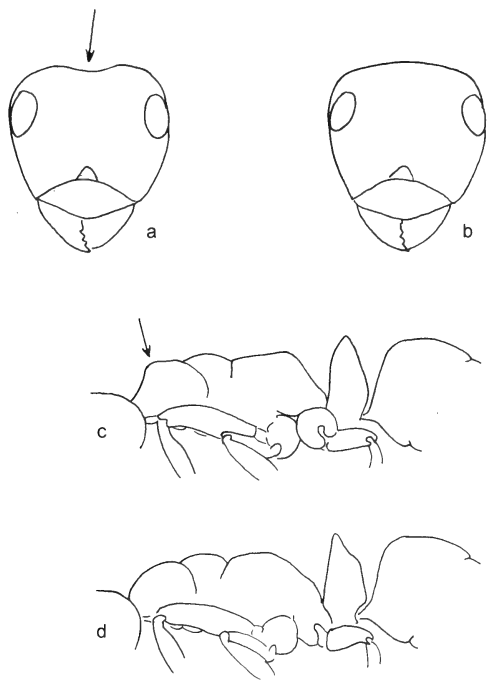
**Figure 10.** Features referred to in the Key to the Major Workers of the Species. a) Clypeus bearing a notch in the ventral border; b) clypeus without a ventral notch; c) profile of a rounded epinotum; b) profile of an angulate epinotum.
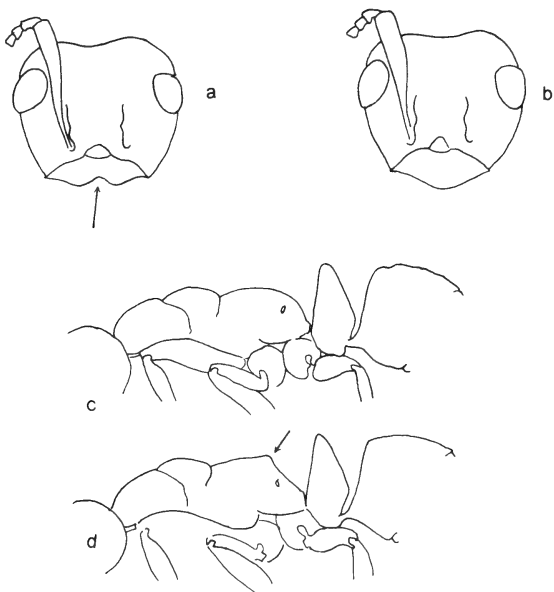


**Figure 11.** Features referred to in the Key to the Major Workers of the Species. a) Concave occipital border; b) non-concave occipital border; c) profile of pronotum with basal and declivitous faces meeting at an angle; d) profile of non-angulate pronotum.
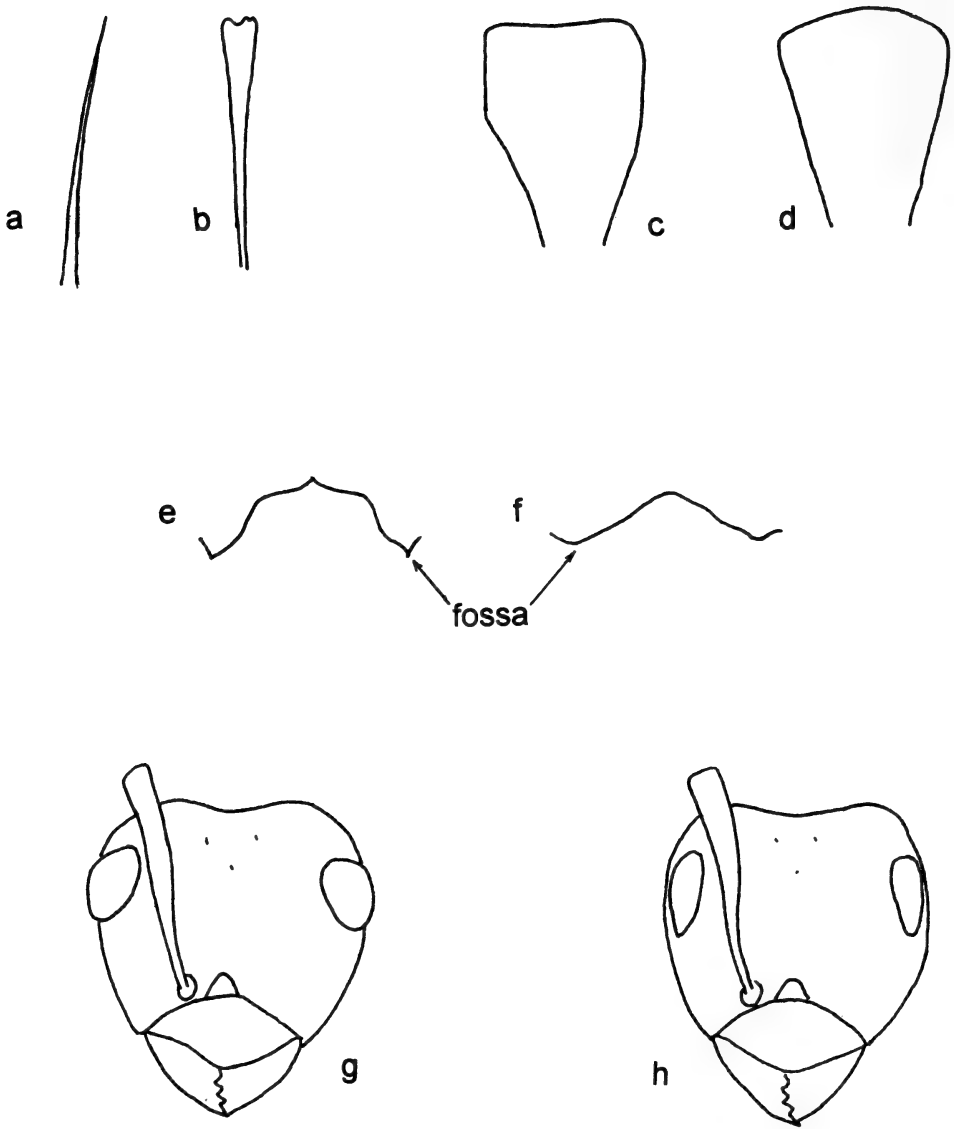
**Figure 12.** Features referred to in the Key to the Major Workers of the Species. a) Pointed, tapering seta; b: spatulate seta; c) posterior view of petiolar scale with a broadly concave crest; d) posterior view of petiolar scale with a convex crest; e) theoretical cross sectional view of the clypeus showing pit-like clypeal fossae; f) shallow clypeal fossae; g) protuberant eyes; h) flattened eyes.

# Key to the Subfamilies of BC Ants

*Based on the worker caste. Adapted and condensed from Hölldobler and Wilson (1990).*

**1**. Body with a single reduced or isolated segment (the petiole) between alitrunk (what appears to be the thorax) and gaster (what appears to be the abdomen) (Fig. 3a)...........................**2**
Body with 2 isolated or reduced segments (petiole and postpetiole) between the alitrunk and the gaster (Fig. 3b)...........................................................................................**Myrmicinae**

**2**. Sting replaced by an acid projecting system of which the acidopore is the orifice. Acidopore at apex of gaster, often projecting as a nozzle and fringed with setae (erect hairs) (Fig. 4a). If concealed, then antennal insertions located well behind the posterior clypeal margin. (The clypeus is the section of the head immediately above the mandibles). ........................................................................................................................**Formicinae**
No acidopore. Antennal fossae (sockets) touching the posterior margin of the clypeus............**3**

**3**. Sting present and functional. Gaster with a distinct constriction between the first and second segments (Fig. 4b)...................................................................................................**Ponerinae**
Sting vestigial or absent. Gaster terminating in a horizontal slit-like opening (Fig. 4c) .................................................................................................................**Dolichoderinae**

# Key to the Genera

*Based on the worker caste. Adapted and condensed from Hölldobler and Wilson (1990).*
**Myrmicinae**

**1**. Antennae with 10 segments, the last 2 forming a distinct club...........................*Solenopsis*
Antennae with 11 or more segments...........................................................................**2**

**2**. Antennae with 11 segments.....................................................................................**3**
Antennae with 12  segments......................................................................................**4**

**3**. Eyes with erect hairs...................................................................................*Formicoxenus*
Eyes lacking erect hairs...........................................................................*Leptothorax* (in part)

**4**. Psammophore (a fringe of long hairs on the posterior surface of the head, usually in seed or nectar-collecting species; Fig. 4d) usually well developed; if absent, erect hairs are often present on the gula (posterior surface of the head) and the alitrunk is extensively and coarsely rugoreticulate (with wrinkles forming a network or grid). Combining following traits: petiolar node set off sharply from the long, distinctive anterior peduncle; the node in side view roughly triangular, usually with a short, steep anterior face, and a longer  gradually sloping posterior face................................................................................................................*Pogonomyrmex*
A true psammophore rarely present, although scattered erect hairs on the gula occur fairly frequently. Anterior peduncle sometimes long, often short or absent. The petiole node in side view variable in shape, often roughly rectangular to quadrate.  In rare cases where the anterior peduncle is long and the node triangular, then alitrunk is not coarsely and extensively rugoreticulate..........................................................................................................**5**

**5**. Dorsum of alitrunk flattened or convex, but without impressed sutures...........................**6**
Dorsum of alitrunk variously shaped in profile, but never forming a continuous surface; its outline always interrupted by one or more sutural impressions......................................**8**

**6**. Frontal carinae long, extending rearward past the eye and reaching or almost reaching the vertex, and/or the clypeus nearly completely covered by conspicuous small, longitudinal wrinkles.................................................................................................................................**7**
Frontal carinae short, not extending past they eye, and never almost reaching the vertex. Clypeus variously sculptured or smooth and shining, but not covered by conspicuous small, longitudinal wrinkles......................................................................................***Leptothorax*** (in part)

**7**. Antennal club 3-segmented..................................................................................***Tetramorium***
Antennal club absent or indistinct.................................................................***Myrmica*** (in part)

**8**. Mandibles with 3 or 4 teeth. Propodeum (posterior region of the alitrunk) lacking teeth or spines.............................................................................................................***Monomorium***
Mandibles with 5 or more teeth. Propodeum frequently bearing teeth or spines...................**9**

**9**. Antenna with a 3 or 4-segmented apical club.............................................................**10**
Antenna lacking an apical club, the terminal segments gradually enlarging towards the apex........................................................................................................................................**11**

**10**. Clypeus with 2 longitudinal carinae (elevated ridges) that do not form teeth on the anterior margin. Workers monomorphic. Propodeum usually armed with small teeth. Antennae with 4-segmented apical club................................................................................................***Stenamma***
Clypeus never with 2 longitudinal carinae. Workers dimorphic, or rarely polymorphic. Majors (soldiers) often with greatly enlarged heads. Antennal club 3-segmented in most species........................................................................................................................***Pheidole***

**11**. Propodeum not armed with teeth or spines, almost always evenly rounded but rarely with small, blunt protuberances. Metanotal region (the narrow transverse band between the propodeum and the region in front of it (the mesonotum) strongly impressed; mesonotum and propodeum forming decidedly separate convexities in profile (Fig. 5a)........................***Manica***
Propodeum armed with teeth (sometimes small) or spines. Metanotal impression variable, sometimes absent (Fig. 5b)....................................................................................................**12**

**12**.Propodeum barely differentiated from remainder of alitrunk and at most slightly depressed below the level of the promesonotum in profile. Antennal scape (the long first segment) often bent abruptly near the base (sometimes nearly 90 degrees) and bearing more or less obvious parallel lines at the bend. In profile, metanotal region weakly to moderately impressed.......................................................................................................***Myrmica*** (in part)
Propodeum usually strongly differentiated from remainder of alitrunk and, in profile, always substantially depressed below the elevation of the pronotum, between which the mesonotum forms a more or less gradually sloping link. Antennal scape not abruptly bent at base, Rarely with lamina at base. Metanotal impression variable. Head longer than broad, and often much narrower behind the eyes than in front of them.............................................***Aphaenogaster***

**Dolichoderinae**
**1**. Metanotal region (narrow transverse band between mesonotum and propodeum) not impressed dorsally. Mesonotum and propodeum forming a smooth, continuous, flat, or convex profile. Ocelli usually present. Workers moderately polymorphic............................***Liometopum***
Metanotal region slightly to strongly impressed dorsally, forming a shallow, concave depression, an angle, or a notch between the mesonotal and propodeal profiles. Ocelli usually absent. Workers monomorphic.........................................................................***Tapinoma***

**Formicinae**

1. Antennae 9-segmented.......................................................……………………...........***Brachymyrmex***
   Antennae 12-segmented.............................................................…………………….............................**2**

2. Mandibles sickle-shaped, with numerous microscopic denticles (tooth-like processes). Petiole with prominent rounded node (not scale-like). Maxillary palps 4-segmented. Slave makers, found in mixed colonies with *Formica* spp.................................................................***Polyergus***
   Mandibles more or less triangular, masticatory margin with 5 - 12 teeth. Petiole usually scale-like, sometimes with a rounded node. Maxillary palps 3 or 6-segmented. Mostly free-living species.....................……………………………………………………………..............................…...................**3**

3. Maxillary palps 3-segmented and very short. Yellow to orange subterranean ants....................
   ……………………………………………………………………………………………...............***Acanthomyops***
   Maxillary palps 6-segmented and moderately to exceptionally long...........……………………......**4**

4. Maxillary palp longer than the head length (excluding the mandibles), the third and fourth segments each as long or longer than the 2 terminal segments combined. Psammophore (an array of long curved hairs beneath the head; Fig. 4d) usually present. In semi-arid habitats..................................………………………………………………………….......***Myrmecocystus***
   Maxillary palp not longer than the head length and usually distinctly shorter, its third and fourth segments not disproportionately long. Psammophore absent.......……………...................................**5**

5. Profile of alitrunk continuous and evenly convex, with propodeum not depressed below the level of the promesonotum (Fig. 5c) and the meso-epinotal suture not or very slightly impressed. Alitrunk in dorsal view wedge shaped and tapering posteriorly........***Camponotus***
   Profile of alitrunk clearly discontinuous and not evenly convex, the meso-epinotal suture always distinct, and the propodeum distinctly depressed below the level of the promesonotum (Fig. 5d). Alitrunk in dorsal view not wedge shaped, usually constricted to some degree in the middle...........................................................................................……………………....................**6**

6. Larger ants; 2.5 - 9 mm long, usually 4.5 - 9 mm. Frontal carinae short but distinct, each a small ridge with a moderately to strongly angulate summit that is slightly reflected upwards. Lower rim of antennal socket nearly touching the posterior border of the clypeus, the distance between them less than 1/4 the maximum diameter of the antennal socket. The basal face of the propodeum usually longer than the downward-sloping one. Ocelli very distinct. Epinotal spiracle a narrow slit................................................................……………………...............***Formica***
   Smaller ants; 2 - 4.5 mm long, usually 2 - 3.5 mm. Frontal carinae indistinct or absent. If present, each carina is a small ridge with a distinctly rounded summit. Distance between the lower rim of the antennal socket and posterior clypeal border commonly 1/3 or greater the maximum diameter of the antennal socket. Downward-sloping face of the propodeum decidedly longer than the basal face, both faces meeting so that the propodeal profile resembles a distinct upwards-facing peak with a more or less rounded apex. Ocelli indistinct or absent. Abdomen often plump. Usually yellow-brown in colour. Epinotal spiracle rounded.........................................................……………………………………………...........***Lasius***

# Key to the Major Workers of the Species

*Adaped from Creighton (1950), Wheeler & Wheeler (1986), and other authors for specific groups (see text).*

## PONERINAE
### Amblyopone
The only species likely to be found locally is..................………………….....……...............***oregonense***

## MYRMICINAE
### Myrmica
**1**. Antennal scape gradually and evenly bent at the base, the upper surface never forming a right
    angle at the end (Fig. 6b)..................…………………………….......…….....................**2**
Antennal scape suddenly bent at base, the upper surface forming a right angle. Lamina
    (Parallel lines) always present, and of various shapes, but never absent from the upper surface
    of the scape (Fig. 6a)..................……………………………………………………….....**3**

**2**. Lateral margins of the frontal lobes, i.e., lobes of the frons, strongly angular, thick and slightly
    but definitely deflected downwards (Fig. 6c). Head and alitrunk with dense pattern of
    grooves (sulci)..................………………………………………….......……....***incompleta***
Lateral margins of the frontal lobes rounded, thin, and moderately to strongly elevated (Fig.
    6d). Colour orange yellow. Distinguished from other members of the genus by short
    propodeal spines and a large inter-lamellar surface on the head............................***brevispinosa***

**3**. Lamina of antennal scape forming a high or wide semicircular flange which surrounds the
    scape where the scape bends (Fig. 7a)..................…………………………….……....***lobifrons***

    Lamina on antennal scape, small and diagonally transverse on the upper surface of the scape,
    but continued as a prominent transparent flange along the inner surface of that part of the
    scape that lies below the bend (Fig. 7b)..................……………….................................***latifrons***

### Manica
**1**. Ventral surface of postpetiole with a prominent tooth (Fig. 7c). Antennal scape surpassing the
    occipital border by an amount equal to its greatest thickness. Colour is deep reddish
    orange..................………………………………………………….......…...............***hunteri***
Postpetiole without a ventral tooth or projection (Fig. 7d). Posterior node of the petiole
    sculpted and dull. Colour is dull yellow to orange.............………………………….......***invida***

### Pogonomyrmex
The only species reported from BC is..................…………………….…….............***salinus***

### Stenamma
**1**. Middle region of the side of the alitrunk (mesopleuron) densely punctate (with many small
    pits) but rugulae (multiple small wrinkles) feeble or lacking. Side of the pronotum with
    conspicuous coarse punctures between the rugulae, the latter often lacking. Basal striae
    (multiple impressed lines) of the first gastric tergite lacking or inconspicuous........***occidentale***
Mesopleuron with several rugulae, interspaces feebly punctate or impunctate. Side of
    pronotum rugulose, the interspaces without punctures or rarely a few fine punctures ventrally.
    The first gastric tergite with distinct basal striae in most specimens................................***diecki***

*Aphaenogaster*
   The only species reported from BC is...............................................................................*occidentalis*

*Pheidole*
   The only species reported from BC is...............................................................................*californica*

*Monomorium*
1. Light reddish-yellow. Head and alitrunk with many small pits. Dull or feebly
   shining..............................................................................................................................*pharaonis*
2. Brownish-black to black. Head and alitrunk mostly, or entirely smooth and strongly
   shining..............................................................................................................................*minimum*

*Solenopsis*
   Collectors are only likely to encounter............................................................................*molesta*

*Leptothorax*
1. Antennae 12-segmented...................................................................................................*nevadensis*
   Antennae 11-segmented.........................................................................................................2

2. Clypeus with a small median carina, or with several. Mesoepinotal suture seldom present on
   the thoracic dorsum and never impressed. Thoracic rugae (wrinkles) well developed. Gaster
   concave at junction with postpetiole..............................................................................*rugatulus*
   Clypeus without a median carina, its center usually depressed to form a shallow, longitudinal
   trough. Mesoepinotal suture regularly present on the thoracic dorsum and usually depressed
   slightly below the level of the alitrunk. Erect setae sparse, short, and usually clavate (club-
   shaped). Interrugal punctures on the alitrunk shallow and sparse, the surface where they
   occur moderately shining. Gaster slightly convex at junction with postpetiole.........*muscorum*

*Formicoxenus*
*Adapted from Francoeur et al. (1985).*
1. Frons and occiput with a reticulated pattern (Fig. 7e). A guest in nests of members of the
   *Formica rufa* species group....................................................................................*diversipilosus*
   Frons and occiput with strong, longitundinal lines (Fig. 7f)...................................................2

2. Sternum of postpetiole not sagitally compressed and as long as high. Propodeal spines longer
   than wide at the base in most specimens. Found in nests with *Myrmica*
   *incompleta*......................................................................................................................*provancheri*
   Sternum of postpetiole sagitally compressed. Propodeal spines shorter than they are wide at
   the base. Found in nests with *Myrmica alaskensis*................................................*quebecensis*

 *Tetramorium*
   The only species likely to be found in BC is..................................................................*caespitum*

**DOLICHODERINAE**
*Liometopum*
   A species reported from BC but unlikely to occur here is..............................................*apiculatum*

*Tapinoma*
   The only species reported from BC is...................................................................................*sessile*

## FORMICINAE
### *Brachymyrmex*
The only species likely to be found locally is.................................……………………….....................*depilis*

### *Camponotus*
**1**. Length of major workers at most 8 mm. Anterior border of the clypeus feebly projecting, depressed in the middle and with a narrow, median notch, behind which is a short, triangular impression..........................……………………………………………………….........................**2**

Length of major workers usually greater than 8 mm. Anterior border of the clypeus not as above, without a median notch in most specimens, but when one is present, there is no impression behind it. ...................……………………………………………….........................…......**3**

**2**. Frontal lobes feebly shining to dull, distinctly shagreened (rough) and punctured. Sides of the head in the larger workers, at most, moderately convex and not unusually narrowed at level of the mandibles.........……………………………………………………………………....*nearcticus*

Sculpture of the frontal lobes shiny and punctured with only faint shagreening. Sides of the head in the major strongly convex and narrowed at the level of the mandible.........……………………………………………………………*hyatti-essigi* complex

**3**. Clypeus distinctly carinate. The antennal scape flattened at the base. Antennal sockets shallow over most of their length. Head (mandibles excluded) as long as broad, or distinctly longer than broad.........……………………………………………………………...…….............**4**

Clypeus not or feebly carinate. Antennal scapes never flattened at the base. Clypeal fossae well marked. Head (mandibles excluded) at least a little broader than long.............................**5**

**4**. Scape distinctly flattened, the flattened portion forming a small lateral lobe (Fig. 8a)…………………………………………………………………….……..*semitestaceous*

Scape also flattened, but lacking the lateral lobe (Fig. 8b). Large ants with red alitrunk and legs, black head and gaster.................……………………………………….............*vicinus*

**5**. Antennal scapes with a number of short, scattered, erect setae. Entire insect jet black and very shining, often with strong bluish reflections.........…………………………………….......*laevigatus*

Antennal scapes without erect setae except for a small cluster at the extreme tip. Color not as above; if all black, the surface is not strongly shining.........…………………………….......**6**

**6**. Antennal scapes reaching or barely surpassing the occipital corners. Alitrunk black anteriorly, red posteriorly. Gaster dull.........................…………………………………….......*herculeanus*

The antennal scapes of the majors surpassing the occipital corners by an amount greater than their greatest diameter.........................……………………………………….......................**7**

**7**. Pubescence on the gaster absent or very fine and sparse, the entire surface of the gaster distinctly shining. Punctures on the head coarse and conspicuous. Head and gaster brownish black, alitrunk red.........……………………………………………………….....*noveboracensis*

Pubescence on gaster coarse, golden, dense, and about half as long as the erect setae. The surface of the gaster dull except for a narrow band at the posterior edge of each segment. Colour is all black.........…………………………………………………….....…………......*modoc*

### *Lasius*
*Adapted from Wilson (1955).*
**1**. Eye large, its maximum diameter 0.20 x head width or more (Fig. 8c).........……………………….....**2**

Eye small, its maximum diameter 0.17 x head width or less (Fig. 8d)........……………….............**6**

**2**. All larger workers and most smaller ones with one or more offset teeth at the basal angle (i.e. closest to the opening of the mouth) of the mandible (Fig. 9a)................................***pallitarsis***
Posterior basal tooth aligned with the other teeth of the masticatory border (Fig. 9b).......….......**3**

**3**. In one or both mandibles of a majority of the workers in a nest, either the penultimate basal tooth is markedly reduced in size relative to the two flanking teeth (Fig. 9c), or the gap between the penultimate and terminal basal teeth tends to be larger in width than the terminal basal tooth (Fig. 9d). When viewed with the mandibles opened and the head held in perfect full face, the anterior border of the median clypeal lobe is angulate, i.e., formed of two straight sides meeting at the midline to from an obtuse, usually pointed angle..............……………............**4**
In all of the workers of a nest, with rare exceptions, the penultimate and terminal basal teeth are subequal in size, and the gap between them has about the same width as the terminal tooth (Fig. 9e). When viewed with the mandibles opened and the head held in full face, the anterior border of the median clypeal lobe is evenly curved, with the sides at least feebly convex and only occasionally meeting at a point at the midline.........................……………………….....................**5**

**4**. The scapes and tibiae bearing erect setae. Body colour light brown to medium brown, very rarely darker...................……………………………………........……............***neoniger***
The scapes and tibiae lacking erect setae and usually without setae of any inclination (but pubescence still present). Colour typically dark brown……………...................................***crypticus***

**5**. For those workers with a pronotal width of 0.53 to 0.7 mm, scapes and tibiae bearing few or no standing hairs; usually less than 10 setae...........……………………..…………….......***alienus***
Within the same size range, scapes and tibiae bearing many setae; the seta count usually greater than 10.................................………………………………...……………...................***niger***

**6**. Eyes with less than 35 ommatidia (facets)...................…………………....................................**7**
Eyes with more than 35 ommatidia.............................................……………...............................**8**

**7**. Outer surface of each tibia with numerous erect setae prominent above the background pubescence.............................…………………………....…………….…....................................***fallax***
Outer surface of each tibia with at most 1 or 2 erect setae...........…………………….......***flavus***

**8**. Setae on posterior half of first gastric tergite, exclusive of the extreme posterior strip, at least in part lying flat or at an angle of less than 45 degrees, and approximately 0.1 mm long. Erect setae sparse or absent on the lateral tibial surfaces…...…….....................................***subumbratus***
Erect setae at posterior half of first gastric tergite, exclusive of the extreme posterior tip, almost entirely erect or suberect, and 0.12 mm or more in length. Erect setae often abundant on the lateral tibial surfaces...................……………………………………………....................***vestitus***

### Acanthomyops
**1**. The antennal scapes, when lying against the head, surpassing the occipital margin by an amount at least as great as the thickness of the tip. Erect setae long and coarse. Gastric pubescence sparse, the gastric surface strongly shining. Erect setae on gastric dorsum 0.23 mm long or longer……………………..........................................................................***interjectus***
The antennal scapes, when lying against the head, not reaching the occiptal margin, or if they do, the amount that projects beyond the margin is less than the thickness of the tip. Erect setae on the gastric dorsum 0.22 mm or less...............................…………………...................................**2**

**2**. Fore femora without erect setae, or when present, mainly confined to flexor surface with only a few inconspicuous erect setae at the base of the lateral surface. Crest of petiole sharp in side view. Most of body and appendages pubescent.......................................................***occidentalis***
Fore femora with erect setae occurring over much of the lateral surface as well as the flexor surface.................…………………………………………………........................................**3**

**3**. Scale of the petiole, in profile, with a blunt crest (Fig. 9f); seen from behind the crest is convex or flattened in the middle but never deeply notched.........................................................***latipes***
Scale of the petiole, in profile, with a thin, sharp crest (Fig. 9g); seen from behind the crest is usually deeply notched in the middle but at least with a distinct medial depression.................…………………………………………..................................***coloradensis***

### *Formica*
### Key to the Major Workers of the Species Groups of *Formica*

*Adapted from Wheeler & Wheeler (1986). Creighton (1950) presented an alternate key that recognized the microgyna species group but it requires inspection of the queens. Wheeler & Wheeler (1986) combined the microgyna and rufa species group so that only examination of the major workers is needed.*

**1**. Ventral border of clypeus notched in the middle (Fig. 10a). Integument dull to feebly shining; pubescence dense, at least on gaster. Bicoloured (except concolorous reddish yellow in *curiosa*), head and alitrunk reddish brown or reddish yellow, gaster brown or black; epinotum short and usually angulate in profile.................................…………………...........***sanguinea*** group
Ventral border of clypeus not notched (Fig. 10b) or if so, pubescence is very sparse and body shining; other characters not all as above..............…………………………………………..........**2**

**2**. Slender; surface shining. Epinotum rounded in profile (i.e., base and declivity not differentiated; Fig. 10c).............…………………………………………………...........***neogagates*** group
Generally robust; surface usually dull. Epinotum usually angulate in profile (i.e., base and declivity clearly differentiated; Fig. 10d)......................………………………………...............**3**

**3**. Larger workers with occipital border distinctly concave (Fig. 11a). Pronotum (in profile) with basal and declivitous bases meeting at an angle (Fig. 11c)....................................***exsecta*** group
Larger workers with occipital border at most slightly concave, usually flat or slightly convex (Fig 11b). Pronotum (in profile) evenly convex, not angulate (Fig. 11d)................................**4**

**4**. Bicoloured; head and alitrunk reddish or yellowish-red and notably lighter than gaster or, if infuscated (with darkened patches), infuscation not completely masking reddish ground colour in larger workers; gaster brown or black; surface mostly dull; (frontal carinae strongly divergent in *rufa* group)..............………………………...................... ***rufa*** and ***microgyna*** groups
Concolourous black or brown or bicoloured; if bicoloured, alitrunk lighter than gaster and upper portion of head; frontal carinae moderately divergent dorsally, often parallel.........................................................…………………………………..….......***fusca*** group

### *Neogagates* Species Group
*Adapted from Wheeler & Wheeler (1986) and Snelling & Buren (1985).*
**1**. Extensor surfaces of the antennal scapes bearing a number of short, very delicate, erect, whitish setae...................................…………………………………………...................…......***lasioides***
Antennal scapes without erect hairs except for a small cluster at the extreme tip........…………....**2**

**2**. Head and alitrunk usually reddish-yellow, gaster black.  Length of largest worker 4.5 mm
............................................................................................................................................***manni***
Gaster black or deep brown, head and alitrunk brownish.  Largest workers 5.5 mm long.........**3**

**3**. Alitrunk paler than head and gaster. Setae on gaster long.  Appressed (lying flat or at an acute
angle) pubescence....................................................................................................................***vinculans***
Alitrunk not paler than head and gaster. Setae on gaster short.   Abundant appressed
pubescence..............................................................................................................................***neogagates***

*Fusca* Species Group
*Adapted from Francoeur (1973) and Wheeler & Wheeler (1986).*
**1**. Metasternum with 2 distinct, seta-covered processes arising on each side of the spinasternal
cavity (a small cavity associated with a pair of spines and located medially, between the
second and third pairs of legs)....................................................................................................**2**
Metasternum without hairy processes...........................................................................................**4**

**2**. Erect setae of gastric dorsum long and flexible, tapering from base to apex. Gastric surface
strongly shining. Workers strongly polymorphic.....................................................***subpolita***
Standing hairs on gastric dorsum short and bristle-like, or the same diameter for most of their
length, then either truncate or abruptly tapered.   Gastric surface feebly shining or dull.
Monomorphic or feebly polymorphic..........................................................................................**3**

**3**. Erect setae present on ventral surface of head, occiput (uppermost part of the head),
propodeum, and epinotum...............................................................................................***montana***
Erect setae absent from ventral surface of head, gena, propodeum, and epinotum .........***neoclara***

**4**. Body concolorous: black, blackish or yellowish brown, or if appearing bicoloured, alitrunk
yellow and very pilose or alitrunk reddish and the upper half of the head black........................**5**
Body bicoloured: head, alitrunk, and petiole reddish or reddish brown, gaster black or blackish
brown.  Surface dull and granulose........................................................................***xerophila***

**5**. The portion of the gena lying between the eye and the insertion of the mandible covered with
coarse, elongate punctures, widely spaced in the posterior half of the gena. The surface
between them covered with coarse lines readily seen under low  magnification. Setae on
gastric dorsum very short and pubescence sparse, at least on the posterior half. Metasternal
setae abundant and surrounding the spinasternal cavity...........................................................**6**
Genae without coarse, elongate punctures, or if present, the punctures are concentrated mostly
in the posterior half of the genae, where they are mixed with fine circular punctures and are
closely spaced.  The surface between them is covered with delicate lines that can hardly be
seen under low magnification.   Setae and pubescence variously combined. Few hairs
surrounding the spinasternal cavity.............................................................................................**7**

**6**. Erect setae abundant, especially on the ventral surface of the head, occiput, prosternum, and
dorsal margin of the petiole and the gastric dorsum. Body brownish black or
black..........................................................................................................................***hewitti***
Few setae, in particular on those structures named above. Anterior half of head and alitrunk
usually reddish...........................................................................................................***neorufibarbis***

**7**. Erect setae abundant, particularly on the ventral surface of the head, occiput, promesonotum, metafemora, dorsal margin of the petiole, and propodeum........................……............................**8**
Erect setae reduced, in particular, absent on propodeum, dorsal margin of the petiole and at least one of the other mentioned structures...............………………………………….......………........**10**

**8**. Occipital angles, and genae with erect setae.............................……………………..........***transmontanis***
Occipital angles, and genae without erect setae.............................………………………............**9**

**9**. Anterior margin of clypeus convex. Crest of petiole, when seen from behind usually without a notch. Head rounded, with convex sides............……………………………………..........………......***aerata***
Anterior margin of clypeus angulate and prominent in the middle. Crest of the petiole usually with a median notch. Head rectangular, with straight sides.........................................***pacifica***

**10**.Erect setae abundant on the first gastric tergite, rarely less than 10 setae, exclusive of the posterior row (mean = 20). Setae around only the posterior portion of the spinasternal cavity..................................…………………………………………............................………….........**11**
Rarely more than 10 erect hairs, excluding posterior row (mean = 4) on the first gastric tergite. Setae surrounding the spinasternal cavity.................……………………………………………........**12**

**11**.Pubescence on the genae and first 4 gastric tergites very dense. Big elongate punctures absent on the genae, beneath and behind the eyes. Pronotum usually with some short, erect setae. Gastric dorsum usually with numerous short and somewhat swollen erect setae. Blackish brown to brown, and about 5 mm long............................................................................***argentea***
Pubescence sparse to normal on the fourth gastric segment and on the genae, at least on the posterior half. Big, elongate punctures present on the genae, beneath and behind the eyes. Black coloured.......................………………………………………………………….……….....***podzolica***

**12**.Antennal scape longer than head. Anterior margin of clypeus angular in most specimens. Diameter of eye 0.43 - 0.54 mm...........................…………………………………......................***accreta***
Antennal scapes often shorter than head length. Anterior margin of the clypeus broadly convex, rarely angular in the middle. Diameter of eye 0.35 - 0.46 mm....................……........***fusca***

***Exsecta*** Species Group
The Peace River region may be home to colonies of.........................………………………............***ulkei***

***Rufa*** and ***microgyna*** species groups
*Adapted from Wheeler & Wheeler (1963, 1986), Gregg (1963), and Creighton (1950).*
**1**. Scapes with erect or suberect setae on all surfaces............................…..…………….....................**2**
Scapes with very few or no erect setae.................…………………………....……………................**3**

**2**. All setae tapering to sharp points; thoracic hairs slender and unequal in length (Fig. 12a).....................................................................…………………………......................***oreas***
Some setae spatulate (spade-shaped) (Fig. 12b); thoracic setae all short and subequal in length........................................................…………………………….................***microgyna***

**3**. Petiolar scale (seen from behind) with a flat or broadly concave crest; sides of upper half of scale parallel, tapering inward only in lower half (Fig. 12c)..................…………….........***dakotensis***
Petiolar scale (seen from behind) with crest convex or angularly produced upward in middle; sides of scale tapering inward from crest to base (Fig. 12d)................................………….........**4**

**4**. Clypeal fossa deep and pit-like (Fig. 12e); edge of clypeus ventral to pit sweeping upward to median lobe; median lobe box-like (i.e., sides descending abruptly to fossae and making angles with its anterior face)...................................................................................................**5**
Clypeal fossa shallow and scarcely pit-like (Fig. 12f); edge of clypeus ventral to pit broadly united to base of lobe and not forming a distinct curve with it; median lobe not box-like (i.e., sides descending to fossae through even curves which begin at carina)...................................**6**

**5**. Middle and hind tibiae with numerous erect setae on all surfaces...................*obscuriventris*
Middle and hind tibiae without erect setae except for double row on flexor surfaces....*laeviceps*

**6**. Erect setae on middle and hind tibiae usually abundant on all surfaces, but there are at least 3 erect setae in addition to those on the flexor surfaces........................................*obscuripes*
Erect setae on middle and hind tibiae, when present, confined to double row on flexor surface, rarely 1 or 2 erect hairs elsewhere.......................................................................................**7**

**7**. Clypeus, gula (posterior surface of head), and gena strongly shining.........................*subnitens*
Clypeus, gula, and gena dull..................................................................................................**8**

**8**. Gula, crest of petiole, and thoracic dorsum usually without erect setae, rarely 1 or 2 inconspicuous setae..................................................................................*haemorrhoidalis*
Pronotum, epinotum, and crest of petiole with numerous erect hairs on many of the workers in a nest.............................................................................................................................**9**

**9**. Erect setae slender and pointed at tip...............................................................*integroides*
Erect setae blunt and spatulate...........................................................................................**10**

**10**. Erect setae never present on crest of petiole; pubescence on gastric dorsum rather sparse and not wholly concealing the surface at the rear edges of the segments; sides of gaster strongly shining..............................................................................................................*whymperi*
Erect setae always present on crest of petiole; pubescence on gastric dorsum dense and wholly concealing surface at rear edge of segments; sides of gaster feebly shining..............................**11**

**11**.The majority of the erect setae on the dorsum of the head and alitrunk notably spatulate and rather short..................................................................................................*spatulata*
Erect setae on the dorsum of head and alitrunk sparse and inconspicuous, when present, blunt at the tip but not notably spatulate, except for a few on the prontum......................*densiventris*

### *Sanguinea* Species Group
*Adapted from Wheeler & Wheeler (1986).*
**1**. Concolourous yellowish red.................................................................................*curiosa*
Bicoloured: head and alitrunk reddish brown or yellow, gaster brown or black.......................**2**

**2**. Dorsum of alitrunk entirely devoid of erect setae or with a few fine, short inconspicous erect setae on pronotum only.............................................................................................*aserva*
Dorsum of pronotum and mesonotum with conspicuous erect setae erect setae usually present on epinotum also......................................................................................................**3**

**3**. Gaster evenly covered with long, stout, silver, erect setae, which are blunt at tip; hairs elsewhere only a little less dense.....................................................................*obtusipilosa*
Erect gastric setae yellow and not notably blunt; erect setae elsewhere much shorter and

sparser.................................……………………………….........................................................**4**

**4**. Eye large and protuberant, its longest diameter approximately 1/3 length of head, in front view
always interrupting lateral border of head (Fig 12g)...............………………………......***curiosa***
Eye flattened, less than 1/3 length of head, in front view not interrupting lateral border of head
(Fig. 12h); pubescence on scape abundant, suberect, and conspicuous......................***puberula***

### *Polyergus*

The only species reported from BC is.......................................……………………......***breviceps***

# Notes on the incidence and host preference of *Dendroctonus punctatus* (Coleoptera: Scolytidae) in spruce forests near Prince George, BC

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## ABSTRACT

*Dendroctonus punctatus* (LeConte) was found to be common, but cryptic, in a survey of spruce stands near Prince George, BC. Characteristics of stands and attacked trees varied considerably, and attacked trees did not differ from healthy trees in the same stand in terms of age, height, or diameter. Attacked trees were normally isolated, but along the edges of two small gaps caused by the root disease-causing fungus, *Inonotus tomentosus* (Fr.:Fr.) S.Teng, we found three and four attacked trees, respectively. All other stands where we found attacks had a high incidence of tomentosus root disease, but we found only two attacked trees which were actually infected by the fungus. The majority of attacked trees displayed basal resinosis, which appeared to be caused by a stain-causing, unidentified pathogen.

**Key words:** boreal spruce beetle, root disease, *Inonotus tomentosus*, host selection

## INTRODUCTION

The boreal spruce beetle, *Dendroctonus punctatus* (LeConte) is a relatively poorly known, transcontinentally distributed bark beetle closely related to the Eurasian *D. micans* (Kugelann) (Wood 1982, Kelley and Farrell 1998). Among native species, it is most similar in habit to the lodgepole pine beetle, *D. murrayanae* Hopkins and, to a lesser extent, the spruce beetle, *D. rufipennis* (Kirby). Single females of *D. punctatus*, probably fertilized in their natal brood chamber, attack standing live trees at very low attack densities. Normally, there is only one attack per tree. This is similar to the habits of *D. micans*. Furniss and Johnson (1989) described the galleries and larvae of *D. punctatus*, and Furniss (1995) provided extensive information on the biology of the species.

*D. punctatus* attacks most boreal species of spruce (*Picea* spp.). Attacks occur at ground level on individual, scattered trees, which range widely in size, but generally are stressed or injured (Furniss 1995). R. Duncan (Canadian Forest Service, Pacific Forestry Centre, Victoria, BC, pers. comm.) indicated that he had found most attacks on waterlogged trees in British Columbia.

During a casual survey of stands near Prince George, we observed an apparent association

between attacks by *D. punctatus* and the widespread root disease *Inonotus tomentosus* (Fr.:Fr.) S. Teng. This fungus is a primary mortality agent in sub-boreal and boreal spruce forests (Lewis 1997). Several important forest pest insect species are suspected to be associated with this disease, e.g., the Warren root collar weevil, *Hylobius warreni* Wood (Whitney 1961, 1962), and *D. rufipennis* (Lewis and Lindgren, pers. obs.).

We determined the incidence of *D. punctatus* attacks in stands of sub-boreal spruce near Prince George, and whether or not it is associated with *I. tomentosus*-infected trees.

## MATERIALS AND METHODS

Seven spruce stands within a 250 km$^2$ area southwest of Prince George were surveyed by random walk-through surveys 29 June - 9 July 1997, and 7-8 July, 1998. Stands with low levels of undergrowth were selected for ease of survey. The bole of spruce trees were examined for evidence of attack, i.e., pitch tubes or brown frass. Particular attention was paid to the area near ground level. In 1997, the bark was carefully removed around the entrance hole, and all life stages collected for additional studies (Grégoire, unpublished data). Attacks were categorized as new if they had fresh, resin-soaked frass at the entrance (unsuccessful attacks) or contained eggs, larvae or pupae, and as old if they contained adults, or were empty but showed evidence of successful brood development, i.e., a large area of the phloem had been consumed. In 1998, the attacks were left undisturbed to facilitate further studies on tree characteristics (Lindgren, unpublished data)

Stand data from variable radius (prism) plots were collected at nine attacked trees in August, 1997, and at five trees in July 1998, and the major roots were examined for evidence of *I. tomentosus* or other root disease.

## RESULTS AND DISCUSSION

Trees attacked by *D. punctatus* were found in every stand visited in 1997. A total of 25 trees were located at seven sites (Table 1). Of these, the majority contained live brood at different stages. In brood chambers with older larvae we frequently found the predatory rove beetle *Hapalaraea longula* (Mäklin) (Coleoptera: Staphylinidae). Only one old attack per tree was found on seven of the attacked trees, whereas there was an average of 2.0 new attacks per tree on 21 trees (some trees contained both old and new attacks). Of these, 11 trees had single attacks, whereas the remaining 10 trees had between 2 and 10 new attacks. In 1998, six trees were located in one of the stands surveyed in 1997 (West Lake Estate Road). Five of these trees had single attacks, one of which had failed. The sixth tree had three attacks.

**Table 1**

Summary data on *D. punctatus* in seven spruce stands near Prince George, 1997.

| Site | # Trees | # Old Attacks | # New Attacks | # Attacks with Brood | | |
|------|---------|---------------|---------------|------|--------|--------|
| | | | | Eggs | Larvae | Adults |
| Blackwater Road | 9 | 5 | 12 | 10 | 2 | 0 |
| Telegraph Trail | 4 | 0 | 4 | 4 | 0 | 0 |
| West Lake | 3 | 0 | 5 | 4 | 1 | 0 |
| West Lake Estate Road | 2 | 1 | 5 | 4 | 1 | 0 |
| Pelican For. Serv. Road, 15 km | 2 | 0 | 4 | 3 | 0 | 0 |
| Pelican For. Serv. Road, 45 km | 1 | 1 | 4 | 4 | 1 | 1 |
| University of Northern BC | 4 | 1 | 15 | 8 | 5 | 1 |
| Mean | 3.5 | 1.1 | 7 | 5.3 | 1.4 | 0.3 |
| Standard Error | 2.44 | 1.64 | 4.2 | 2.43 | 1.59 | 0.45 |

Twelve of the 14 attacked trees at which stand data were collected were hybrid white x Engelmann spruce, *Picea glauca x engelmanni* (Parry) Engelmann, while the remaining two were black spruce, *Picea mariana* (Miller) Britton. Attacked trees varied considerably in size with a mean (± 1 SD) diameter at breast height (dbh) of 22.5 (± 4.0) cm for hybrid spruce (N=12), and 16.2 (± 3.89) cm (N=2) for black spruce. The dbh of attacked trees ranged from 75 - 140 % of the mean dbh for that species in the stand. The five hybrid spruce measured in 1998 had a mean (± 1 SD) height of 18.7 (± 2.65) m. Four of these trees were aged by counting the rings on increment cores. The age of these trees ranged from 80 to 140 years, with a mean (± 1 SD) of 102.5 (± 26.3) years. These data are similar to those of Furniss (1995), and did not differ from unattacked trees of similar diameters in the same stand (mean age = 103.0 ± 26.8 years, N=5).

Stand structure varied considerably, with some stands having a closed canopy while others had an open structure. Spruce was the leading species in all cases, but since stands were selected on the basis of spruce dominance, we cannot determine to what extent stand structure influences the presence of *D. punctatus*.

Many of the attacked trees showed signs of decline, e.g., thinning and/or chlorotic foliage, short leaders, stress cone crops, etc., which is in agreement with Furniss (1995). No attacks were found in waterlogged areas. Attacks were found along the edges of tomentosus root disease pockets in two cases, where we found three and four attacked trees respectively. Tomentosus root disease was prevalent in all stands surveyed, although we did not quantify its incidence. Of nine attacked trees examined by KL, only two showed signs of infection by *I. tomentosus*. One declining, attacked hybrid white spruce had one root affected by a sap rot, possibly caused by *Armillaria sinapina* (Bérubé and Dessureault), and in another case three of four major roots had advanced brown rot. In another tree three of four roots were dead, without a visible cause of death. A small black spruce had no visible disease on the major roots. The majority of the attacked trees had resin streaming down the lower trunk. Generally the area of resin flow extended 50-100 cm up from the ground on one side of the trunk. When the bark was removed on these trees, a dark brown stain, similar to the stain caused by *Phytophthora* spp. was evident. Attacks were consistently located near the stained area, but not directly associated with it. Similarly, trees affected by other diseases sustained the attacks on the lower bole between healthy and diseased roots. All trees located in 1998 exhibited external resin flow. An attacked tree located during another study near Mackenzie, BC, 13 May, 1998, also had external resin flow and the associated stain. This tree yielded 29 adults. Also, two unsuccessful attacks were noted on a dead hybrid spruce infected by *Phellinus pini* (Thore:Fr.)Ames.

*D. punctatus* life stages found in 1997 agree with the life cycle interpretation by Furniss (1995). We found a high proportion of successful attacks, but it is possible that unsuccessful attacks are less evident, and therefore may be missed. Of the attacks located in 1998, only one (an old attack yielding 54 brood adults) was successful. Furniss (1995) found that only half of the attacks he investigated were successful.

Based on our findings, it appears that *D. punctatus* prefers to attack weakened trees, and that root diseases play a major role as predisposing agents. *Inonotus tomentosus* does not appear to directly predispose trees to attack by *D. punctatus*, but may do so indirectly by predisposing trees to invasion by the stain we observed. This would explain why we found several attacked trees in close proximity around the perimeter of two *I. tomentosus*-caused gaps.

We conclude that *D. punctatus* is widespread in sub-boreal spruce forests, and that it is most commonly associated with diseased trees. Attacks are probably often mis-diagnosed as single attacks by the spruce beetle, *Dendroctonus rufipennis*, by those unfamiliar with *D. punctatus*. Trees with basal resinosis, particularly along the edges of tomentosus root-disease gaps are most

likely to be attacked by this bark beetle.

# ACKNOWLEDGEMENTS

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# Attraction of *Pissodes affinis* and *P. fasciatus* (Coleoptera: Curculionidae) to pityol and α-pinene in a coastal stand of western white pine and Douglas-fir

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## ABSTRACT

Lindgren multiple-funnel traps, baited with (-)-α-pinene and (±)-pityol, captured significant numbers of the weevils, *Pissodes affinis* Randall and *P. fasciatus* LeConte, in a coastal stand of Douglas-fir and western white pine.

**Key words:** *Pissodes*, Coleoptera, Curculionidae, pityol, Lindgren funnel trap

## DISCUSSION

During a 3-week period in early summer of 1997, 22 *Pissodes affinis* Randall and 16 *P. fasciatus* (LeConte) (Coleoptera: Curculionidae) were captured in one Lindgren 12-unit multiple-funnel trap (Lindgren 1983), baited with (-)-α-pinene and (±)-pityol, (2*R*, 5*S*)-2-[1-hydroxyl-1-methylethyl]-5-methyl-tetrahydrofuran. Eight additional funnel traps baited with (-)-α-pinene and ethanol, or ethanol alone, did not capture any weevils. The traps, located near ground level within a 25-30-year-old stand on Texada Island, British Columbia, were extraneous to a trapping study on the attraction of the ponderosa pine cone beetle, *Conophthorus ponderosae* Hopkins (Coleoptera: Scolytidae), to the sex pheromone (±)-pityol in the crowns of western white pine, *Pinus monticola* Dougl. ex D. Don (published elsewhere). The sole purpose of the nine Lindgren funnel traps was to collect a sample of various species of beetles that occur within a stand dominated by western white pine and coastal Douglas-fir, *Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco. The lack of replication in the serendipitous capture of a significant number of weevils necessitated additional research in order to assuage concerns that the result was due solely to random chance, prior to directing a comprehensive effort on the chemical ecology of these two species. Therefore, in 1998 we attempted to verify the attraction of *P. affinis* and *P. fasciatus* to Lindgren multiple-funnel traps baited with (-)-α-pinene and (±)-pityol.

Twenty 12-unit Lindgren multiple-funnel traps (Phero Tech Inc., Delta BC) were set in the same Texada Island study area used in 1997. The 12-ha stand is a seed production area for western white pine resistant to white pine blister rust, *Cronartium ribicola* J.C. Fisch. The mean (± SE) height and diameter (at breast height) of white pine trees were 21.5 (± 0.3) m and 31.3 (± 1.1) cm. Each trap was hung between two trees with twine such that the bottom of each trap was approximately 0.5 m above ground level as in 1997. No trap was within 2 m of any tree. Spacing between traps varied from 10-15 m. Each

collection cup had a side-mounted screen for drainage and contained ca. 200 mL of plumber's antifreeze (a.i. propylene glycol).

Ten randomly-selected traps were baited with (±)-pityol (40 mg bubblecap lure) and (-)-α-pinene (15 mL polyethylene bottle) (Phero Tech Inc., Delta, British Columbia), both with chemical purities >98%. The release rates of (±)-pityol and (-)-α-pinene from lures were ca. 0.2 mg/d and 150 mg/d, respectively, at 24 °C. The remaining traps were not baited. Trapping commenced on 15 April with catches collected at intervals of 2-3 weeks until the traps were taken down on 20 August. Voucher specimens were deposited at the Entomology Museum, Pacific Forestry Centre (Victoria, British Columbia). Trap catch data were analyzed by $t$-test at the 5% probability level with the SYSTAT statistical package version 8.0 (SPSS 1998).

Both *Pissodes affinis* and *P. fasciatus* were attracted to traps baited with (-)-α-pinene and (±)-pityol; no weevils were captured in unbaited traps (Table 1). Most weevils (92%) were captured between 15 May and 31 July while none were caught during the last collection period (1-20 August). The total catch of 54 weevils in the stands in 1998 is consistent with the total catch of 38 weevils in 1997 although the mean trap catch of weevils was low.

**Table 1**

Total catches of *Pissodes affinis* and *P. fasciatus* to baited Lindgren multiple-funnel traps from 15 April to 20 August 1998 ($n$ = 10).

|                    | Mean (±SE) number of weevils[a] | |
|--------------------|:------------------------------:|:-----------------------:|
| Species            | Blank control                  | Pityol + α-pinene       |
| *Pissodes affinis*   | 0.0 ± 0.0 a                     | 3.1 ± 1.0 b             |
| *Pissodes fasciatus* | 0.0 ± 0.0 a                     | 2.3 ± 0.5 b             |

[a] Means within the same row followed by a different letter are significantly different at $P<0.05$ ($t$ test).

Low trap catches are not uncommon with *Pissodes* weevils. Mean catches to the popular sticky, cylindrical, mesh traps have ranged from 6-19 weevils/trap/season, sometimes higher depending on population levels and attractants (eg. Overhulser and Gara 1975; Fontaine and Foltz 1982; Booth *et al.* 1983; Phillips and Lanier 1986). Tunset *et al.* (1993) caught 9-12 *P. pini* (L.)/trap/season with window traps while Chénier and Philogène (1989a) caught ca. four *P. strobus* (Peck)/trap/season with similar traps; they caught less than one weevil/trap/season with the Lindgren multiple-funnel trap. Pitfall traps also catch low numbers of weevils (9-12/trap/season) (Nevill and Alexander 1992).

*Pissodes affinis* and *P. fasciatus* are root/bole weevils that feed on western white pine and Douglas-fir, respectively (Furniss and Carolin 1980). *Pissodes fasciatus* vectors black-stain root disease, *Leptographium wageneri* (Kendrick) M.J. Wingfield, in Douglas-fir (Witcosky and Hansen 1985; Witcosky *et al.* 1986; Jacobi 1992), a disease which causes significant mortality in young stands (15-30 yrs) (Hunt and Morrison 1995; Allen *et al.* 1996). An effective monitoring tool for these species would be useful in attempts to understand their possible impacts and opportunities for controls. Our results offer promise that an effective trapping tool can be developed for *P. fasciatus* and *P. affinis.*

Issues such as trap design and density, and optimal combinations of lures and release rates need to be resolved for *P. affinis* and *P. fasciatus*. Chénier and Philogène (1989a) found that sticky, stovepipe traps were significantly more effective in catching *P. strobus*

and *Hylobius pales* (Herbst) than either window traps or Lindgren funnel traps. In Florida, Fatzinger (1985a) caught in excess of 12,000 weevils of various species with 21 traps consisting of wading pools and stovepipe cylinders. Various authors have demonstrated synergism between ethanol and monoterpenes in the attraction of weevils (Fatzinger 1985b; Tilles *et al.* 1986; Fatzinger *et al.* 1987; Chénier and Philogène 1989b; Hunt and Raffa 1989; Rieske and Raffa 1991). It is also possible that the propylene glycol used in collection jars acted as a synergist. Propylene glycol is a human food product and may represent a food source to weevils as well. Moreover, low catches of weevils in past trials using Lindgren multiple-funnel traps without a liquid preservative may have been a consequence of escapes by weevils due to their high level of agility, relative to other beetle species commonly captured in multiple-funnel traps.

# ACKNOWLEDGEMENTS

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# Adult eclosion, flight and oviposition of *Choristoneura rosaceana* (Lepidoptera: Tortricidae), in British Columbia apple orchards

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## ABSTRACT

Adult eclosion and oviposition of obliquebanded leafroller, *Choristoneura rosaceana* (Harris), was studied under field conditions so that integrated pest management of this species could be appropriately timed. Seasonal flight activity of adult males was monitored with synthetic pheromone-baited traps in unsprayed, organically grown apple, *Malus domesticus* (Borkh.) orchards in the Similkameen (1994-1997) and Okanagan (1996-1997) Valleys of British Columbia. Eclosion of adults from collected larvae and oviposition of female moths was monitored by daily observation in the 1996 and 1997 field seasons to establish relationships between insect phenology and accumulated degree days above 10°C ($°dd_{10°C}$) air temperature after 1 January. Males emerged before females throughout the eclosion period in both years. First catches of males in pheromone-baited traps preceded first-male eclosion of collected males by 7 and 6 $°dd_{10°C}$ in 1996 and 1997, respectively, after which cumulative percentages of trap capture lagged behind cumulative percentages of male eclosion in both years. First and second male flight periods had similar durations in the Similkameen Valley, varying from 481-636 and 476-779 $°dd_{10°C}$, respectively. Mean ($\pm$SE) initiation of oviposition was 29 $\pm$ 2.2 $°dd_{10°C}$ after the first female eclosed. The nonlinear relationships between plots of cumulative adult emergence, oviposition and trap catch against $°dd_{10°C}$ after 1 January were modelled using Weibull functions. Fifty percent adult eclosion was predicted to occur at 328 and 335 $°dd_{10°C}$ after 1 January for males and females in the overwintered generation, respectively. Fifty percent male and female eclosion in the summer generation was predicted to occur at 843 and 909 $°dd_{10°C}$ after 1 January. Fifty percent oviposition was predicted at 91 $°dd_{10°C}$ after first female emergence. Models of the trap catch in the Similkameen and Okanagan Valleys were similar and predicted 50% of the first flight at 438 (Similkameen) and 485 (Okanagan)$°dd_{10°C}$ after 1 January. Prediction of the occurrence of adult obliquebanded leafroller eclosion, mating and oviposition will aid in the development of a pheromone-based, integrated pest management programme for *C. rosaceana* in British Columbia.

**Key words:** *Choristoneura rosaceana*, phenology, mating, oviposition, pheromone

## INTRODUCTION

*Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae) overwinters as a diapausing larva in protective hibernacula on woody host plants (Chapman *et al.* 1968). Diapause is

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facultative (Chapman *et al.* 1968), allowing for additional generations if conditions are favourable. In British Columbia (BC), overwintering larvae break diapause early in the spring and resume development through the remainder of six instars. Adult flight in BC, usually starts in early June and mating and oviposition are presumed to occur from mid-June to August. The second adult flight begins in August and continues until October (Madsen and Proctor 1985). Eggs are laid during this period and larvae that emerge in September and October overwinter in diapause.

The number of generations each year varies by location: two in New York (Chapman *et al.* 1968), southern Québec (Delisle 1992; Hunter and McNeil 1997) and Oregon (AliNiazee 1986), but only one in northern Québec (Hunter and McNeil 1997), Nova Scotia (Sanders and Dustan 1919) and Utah (Knowlton and Allen 1937). In BC, Venables (1924) reported that *C. rosaceana* is univoltine but Madsen *et al.* (1984) suggested that it is univoltine in the northern Okanagan Valley and at higher elevations, and is bivoltine in the southern Okanagan and Similkameen Valleys. The quality of the host plant influences the proportion of *C. rosaceana* that enter diapause (Hunter and McNeil 1997), which may contribute to variable voltinism in the same area.

The obliquebanded leafroller can cause fruit injury during several time periods. Emergent overwintered larvae can cause premature fruit drop, or deep russetted scarring of the apple (Reissig 1978). Summer-generation larvae cause damage by tying leaves to the surface of fruit under which they feed, resulting in irregular scars on the fruit (Madsen and Proctor 1985). Summer feeding damage can be more serious than that from overwintering larvae, because most damaged apples remain on the tree at harvest (Reissig 1978).

Control of the codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) by the Sterile Insect Release programme (Dyck *et al.* 1993) or by pheromone-based mating disruption (Judd *et al.* 1996a, 1997) in the Okanagan, Similkameen and Creston Valleys of BC will reduce insecticide application in orchards and may elevate the pest status of *C. rosaceana* and other leafroller species. The leafroller-eyespotted budmoth (Lepidoptera: Tortricidae) complex in BC can cause 10-20% damage in untreated orchards (Judd *et al.* 1992). In an effort to benefit from non-insecticidal control of *C. pomonella* and produce insecticide-free fruit, growers would like to apply organic methods for managing *C. rosaceana* and other tortricine leafrollers, such as pheromone-based mating disruption. In order to schedule pheromone applications so that they are effective at the time of mating and oviposition, information on the developmental physiology of this insect is required.

AliNiazee (1986) developed a degree-day (°dd) model for predicting seasonal flights of male *C. rosaceana* as measured by moth capture in pheromone-baited traps. In a laboratory study, Gangavalli and AliNiazee (1985a) demonstrated that female *C. rosaceana* laid eggs 35.2 $°dd_{11.9°C}$ after eclosion, egg development from oviposition to hatch took 111.9 $°dd_{10°C}$, larvae needed 435.6 $°dd_{10°C}$ to complete development through six instars, and pupae eclosed after 117.4 $°dd_{10°C}$. Reissig (1978) developed a temperature-driven model to predict egg hatch based on when the first male moth was captured in pheromone-baited traps; this biological indicator is referred to as a "biofix". Onstad *et al.* (1985) developed a model to predict a critical number of larvae hatching to time spray applications. The crucial developmental information required to implement a pheromone-based mating-disruption programme is eclosion of female moths and timing and duration of mating and oviposition in the field.

Our objectives were to determine when adults of both sexes of both generations of *C. rosaceana,* held under field conditions, eclosed and the onset and duration of oviposition on a physiological °dd scale.

## MATERIALS AND METHODS

**Larval Development.** In 1996, active larvae were collected from shoot terminals in an organic

apple orchard in Cawston (49°11' N, 119°46' W), in the Similkameen Valley, from 5 through 8 May, corresponding to 87-89°$dd_{10°C}$ accumulated from 1 January. Larvae were collected throughout the orchard, placed in paper bags, transported to the laboratory in refrigerated containers, and transferred in groups of 5-10 into cylindrical sleeve cages (50 cm long x 20 cm diameter) made from white nylon organza mesh. Each cage was secured at both ends over a leaf-bearing branch about 2 m above ground on cultivar Red Delicious apple trees in an experimental orchard at the Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, in the Okanagan Valley at Summerland, (49°34' N, 119°39' W) for the completion of larval development. Caged larvae were moved to a fresh branch when necessary to ensure an adequate supply of apple leaves.

Larvae were collected in 1997 from the same orchard as in 1996. Sixty apple trees were sampled weekly for active larvae from 6 May through 3 June, corresponding to 76-259 °$dd_{10°C}$ accumulated from 1 January. Sampled trees were spaced evenly throughout the orchard and both edge and interior trees were included. A sample consisted of a 5 min full-tree search for larval nests, leaves or petals webbed together, which were removed during the sample. Collected larvae were stored, transported, and reared in groups of 10-20 in mesh cylindrical sleeve cages as in 1996.

**Adult Eclosion.** Once pupae were detected, caged branches were cut from the tree and sleeve cages and leaves were carefully inspected for pupae and larvae. Searches for pupae were repeated weekly after the onset of pupation from 29 May through 24 July, 1996 and from 21 May through 9 July, 1997, until all larvae had pupated.

In 1996, pupae retrieved from sleeve cages were separated by sex and transferred to a mesh emergence cage with a wooden frame (28 x 28 x 37 cm), located on a platform 1.4 m above ground within the tree canopy in the Summerland orchard. The cage was checked daily for newly-eclosed adults. Adults were sexed and two out of every three males and females were transferred to a mesh oviposition cage with an aluminum frame (44 x 41 x 41 cm) placed on a platform 1.4 m above ground within the tree canopy in the orchard. In the oviposition cage, moths were provided with 3-4 freshly excised apple twigs placed in water as an oviposition substrate and dental cotton wicks in flasks of distilled water as a water source. The remaining adults were transferred to a bottomless field cage (3.6 x 3.6 x 2.4 m) enclosing a small apple tree, that had previously been stripped of all leafroller larvae, to mate and produce larvae as a collection source for the summer generation.

In 1997, pupae retrieved from sleeve cages were separated by sex and transferred to emergence cages as in 1996, but were segregated into five cages by larval collection date. Newly-eclosed adults were collected daily, enumerated by sex, transferred to a communal oviposition cage (44 x 41 x 41 cm) placed on a platform 1.4 m above ground, within the tree canopy in the same orchard, and provided with apple branches and water as in 1996.

In both years, summer generation larvae were searched for within the field cage. In 1997, larvae were collected and arranged in sleeve cages following the same protocol as for the overwintered generation. Adult moth eclosion from the summer generation was monitored only in 1997, as too few individuals were recovered in 1996.

**Male Moth Flight.** Two monitoring traps were hung in the Summerland orchard on 31 May 1996 and 7 June 1997. Traps were constructed from opposing wing-trap tops (Phero Tech Inc., Delta, BC) held 5 cm apart with pieces of drinking straw. Stickem Special® (Phero Tech Inc.) was thinly applied to the inside surface of the trap bottom (an inverted top) to capture moths. Lures were suspended from the inside tops of traps using a straight pin. Traps were hung by a wire hanger from trees approximately 1.5 m above ground. Lures used to monitor *C. rosaceana* consisted of a 100:2:1.5:1 ratio of Z11-14:OAc : E11-14:OAc : Z11-14:OH : Z11-14:Ald (Vakenti *et al.* 1988; Thomson *et al.* 1991) loaded onto red rubber septa (The West Company, Linville, PA) at a rate of 3 mg in 200 µl of HPLC-grade hexane per septum. Lures were replaced

every four weeks during the flight period. Traps were checked daily throughout the first flight in 1996 and for both flights in 1997. Each day, trap bottoms with captured males were removed and replaced with fresh bottoms. Monitoring traps were also placed in three orchards in Cawston, from 1994-1997 and checked at 2-3-day intervals throughout the flight period. Trap catches from sites at each location were pooled at each site prior to analysis.

**Oviposition.** Excised apple branches in the oviposition cages were checked daily, inspected for egg masses and replaced with freshly cut branches. In 1996, egg masses were counted, labelled, transported to the laboratory for enumeration of eggs and discarded. In 1997, egg masses were counted, labelled and transferred to a (3.6 x 3.6 x 2.4 m) field cage covering a small apple tree which had previously been stripped of all leafroller larvae. Larvae emerging from these egg masses were used as a collection source for the summer generation. Monitoring of the oviposition period of summer generation females was conducted in 1997 only, using the same protocol as for the overwintered generation.

**Weather Data.** Hourly air temperatures were recorded year-round in Cawston at an orchard located approximately 1 km from the orchard in which larvae were collected, and in the Summerland orchard using DP-212 datapods (Omnidata, Logan, Utah) housed in standard-height (1 m) Stevenson screens placed in the centre of each orchard. When temperature data were missing due to malfunction of equipment, replacement data were obtained for the Similkameen Valley site from Integrated Crop Management (Cawston) or Environment Canada (Keremeos), and from the Okanagan Valley site from Agriculture and Agri-Food Canada (Summerland). Daily °dd summations for each location and year were calculated by fitting a sine wave (Allen 1976) to daily temperature minima and maxima using the computer programme described by Higley *et al.* (1986). A lower base temperature of 10°C and upper threshold temperature of 31°C were chosen, based on developmental data for *C. rosaceana* (Gangavalli and AliNiazee 1985a). Degree day accumulations were started on 1 January of each year instead of after the first trap catch (biofix) because larvae originated in a different location from where adults emerged. The difference in °dd accumulations between Cawston and Summerland was added to the °dd accumulations at Summerland, when larvae were moved to this more northerly location.

**Statistical Analyses.** Daily trap catches, and eclosion of males and females at Summerland in both years were converted to cumulative percentages of total generational trap catch, or eclosion, respectively, and plotted against $°dd_{10°C}$ accumulated from 1 January. Due to low levels of eclosion, cumulative percentages could not be calculated for the summer generation trap catch or eclosion in 1996 or for trap catch in 1997. A non-parametric, two-sample Kolmogorov-Smirnov test was used to test the hypothesis that the cumulative distributions for eclosed adult males and females were equivalent (Conover 1971). The test statistic, $T$ is defined as the greatest vertical distance between the two empirical distribution functions $S_1$ and $S_2$, which were obtained by a random sample (Conover 1971).

To determine if the number of egg masses deposited was an adequate measure of total eggs laid, the number of $°dd_{10°C}$ accumulated after first female emergence in 1996 was regressed against the number of eggs per sampled egg mass (SAS 1996). The number of eggs per mass did not change throughout the oviposition period ($r^2$=0.0650) so all calculations in 1996 and 1997 were conducted on the number of egg masses laid. The numbers of egg masses produced daily were converted to cumulative percentages of the total number of egg masses produced per generation and plotted against $°dd_{10°C}$ accumulated from the first female emergence. Cumulative percentages were not calculated for summer-generation oviposition in 1996.

The nonlinear relationship between female eclosion, male eclosion, oviposition or trap catch and temperature was modelled with cumulative Weibull functions (Wagner *et al.* 1984). This technique has been used to describe the relationship between temperature and insect development and eclosion in other species (Wagner *et al.* 1984; Cockfield *et al.* 1994; Judd *et al.* 1996b; Judd and Gardiner 1997; McBrien and Judd 1998).

A cumulative Weibull function of the form:

$$f(x) = 100\left[1 - \exp^{-(x/a)^b}\right] \quad \text{[Equation 1]}$$

in which, $f(x)$ is the cumulative percentage eclosion, oviposition or trap catch, $x$ is the predictor variable (time or degree days), and $a$ and $b$ are parameters to be estimated. Estimated values for parameters were determined using the nonlinear regression procedure in SigmaStat™ (1994).

# RESULTS

**Adult Eclosion.** Similar numbers of male and female *C. rosaceana* eclosed in 1996 and 1997 (Table 1), indicating a 1:1 sex ratio in nature. In both years, the first males emerged before the first females. The cumulative distributions of percent male and female eclosion were significantly different for overwintered-generation moths in 1996 ($T_{60,60}$ = 0.2483, $P$< 0.05) and in 1997 ($T_{114,130}$ = 0.15526, $P$< 0.05). In 1996 and 1997 the first male moths of the overwintered generation eclosed at 221 and 255 $°dd_{10°C}$, respectively, 18 and 7 $°dd_{10°C}$ before first female moths. Fifty percent of overwintered-generation males in 1996 and 1997 eclosed 26 and 19 $°dd_{10°C}$ respectively, before 50% of the females eclosed, indicating protandry throughout the eclosion period. Summer-generation eclosion could only be followed in 1997 (Table 1), as too few individuals were recovered in 1996. As in the overwintered generation, males eclosed before females ($T_{12,19}$ = 0.4722, $P$< 0.05). Few larvae that emerged from egg masses deposited by the collected individuals developed through to summer-generation adults in 1997, suggesting that most summer-generation larvae entered diapause in 1997. This is supported by the collection of 288 larvae that emerged on this same caged tree the following spring, 1998 (Evenden, unpubl. data). Adult male and female eclosion in the overwintered generation modelled using Weibull functions described the within year eclosion accurately for both sexes; however, these functions did not fit the multiple-year data well (Fig. 1).

**Table 1**

Total number of adult *C. rosaceana* eclosing (Ec) and trapped (Tr) in 1996 and 1997, and observed $°dd_{10°C}$ from January 1, 1996 and 1997 for various eclosion and trapping events.

| | | | No. of insects | | First occurrence | | 5th percentile | | 50th percentile | | 95th percentile | |
|------|--------|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|
| Year | Flight | Sex | Ec | Tr | Ec | Tr | Ec | Tr | Ec | Tr | Ec | Tr |
| 1996 | 1 | ♀♀ | 60 | | 239 | | 246 | | 290 | | 428 | |
| | | ♂♂ | 60 | 3714 | 221 | 214 | 221 | 306 | 264 | 452 | 335 | 635 |
| 1997 | 1 | ♀♀ | 130 | | 262 | | 285 | | 347 | | 473 | |
| | | ♂♂ | 114 | 4169 | 255 | 249 | 279 | 332 | 328 | 530 | 482 | 691 |
| | 2 | ♀♀ | 16 | | 843 | | 843 | | 909 | | 1000 | |
| | | ♂♂ | 12 | | 741 | | 741 | | 843 | | 929 | |

The columns labeled "Observed $°dd_{10°C}$" span First occurrence, 5th percentile, 50th percentile, and 95th percentile.

**Male Moth Flight.** First trap catches of males in the Summerland orchard occurred at 214 and 249 $°dd_{10°C}$ in 1996 and 1997, respectively (Table 1). The first male trap catch preceded first male eclosion in captivity by 7 and 6 $°dd_{10°C}$ in 1996 and 1997, respectively, which corresponded to only 1 calendar day in both years. Despite the congruence between first trap capture and first
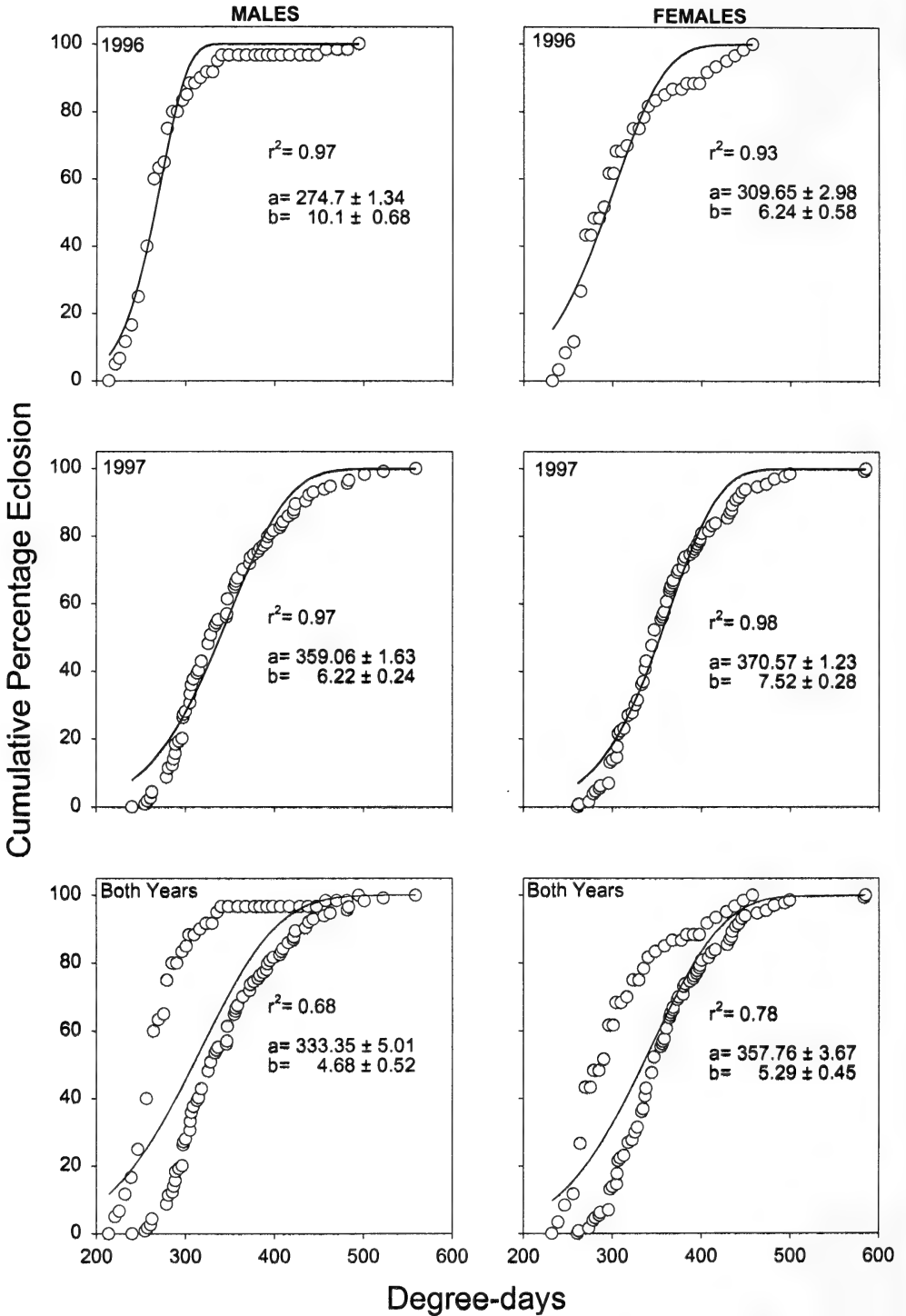
**Figure 1.** Observed cumulative first-generation *Choristoneura rosaceana* adult eclosion (o) in 1996 and 1997 alone and combined, plotted against $°dd_{10°C}$ air temperature after 1 January compared with curves (solid lines) modelled by Weibull functions with estimated parameters a and b (see text).
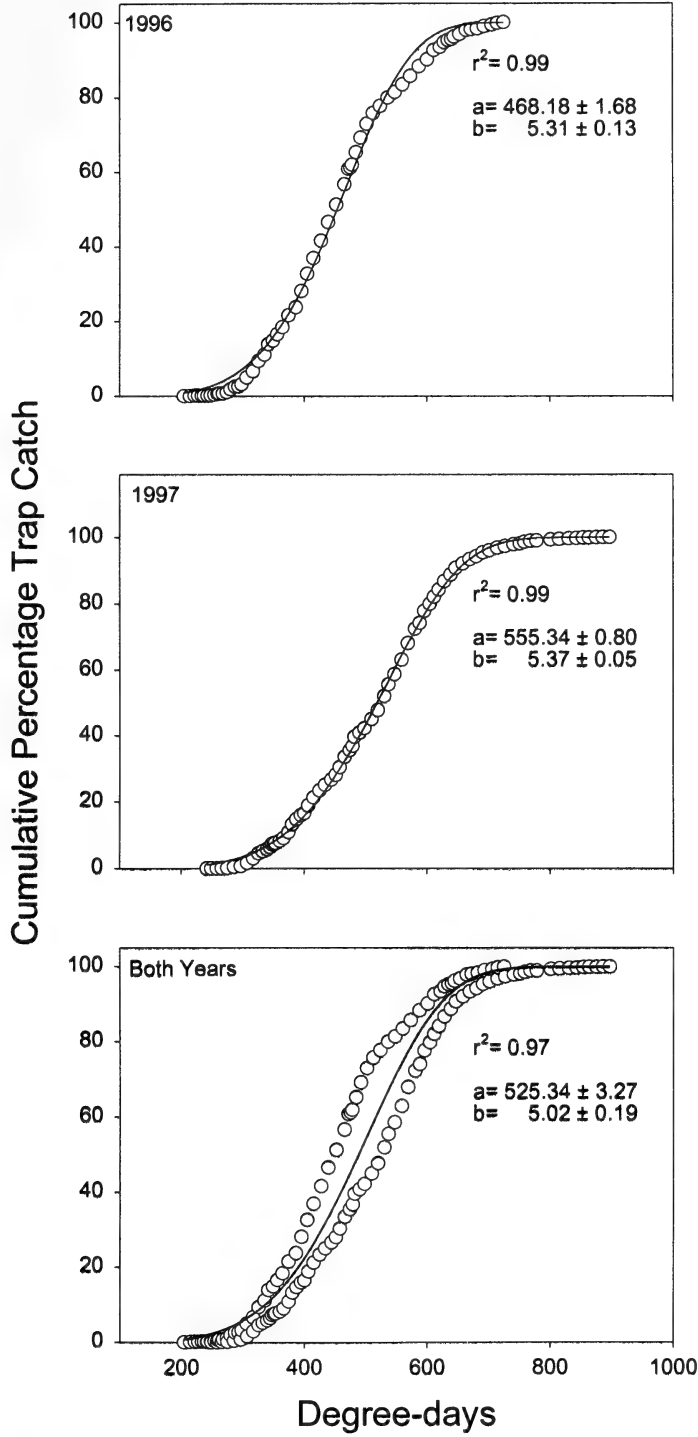
**Figure 2.** Cumulative trap captures of first-generation male *Choristoneura rosaceana* (o) in pheromone traps at Summerland during 1996 and 1997 alone and combined, plotted against °dd$_{10°C}$ air temperature after 1 January, compared with curves (solid lines) modelled by Weibull functions with estimated parameters a and b (see text).

male eclosion, cumulative percentages of males captured in traps lagged behind cumulative percentages of male eclosion in 1996 and 1997 (Table 1). First male trap catch preceded first captive female eclosion by 25 and 14 $°dd_{10°C}$, corresponding to 5 and 2 calendar days in 1996 and 1997, respectively (Table 1). Cumulative percentage curves of male trap captures in 1996 and 1997 also lagged behind female eclosion in captivity.

Weibull functions accurately described cumulative percentages of first-flight trap capture at Summerland in 1996 and 1997 and for both years combined (Fig. 2). Similarly, a Weibull function fitted the cumulative percentages of first-flight trap capture in Cawston over a 4-year
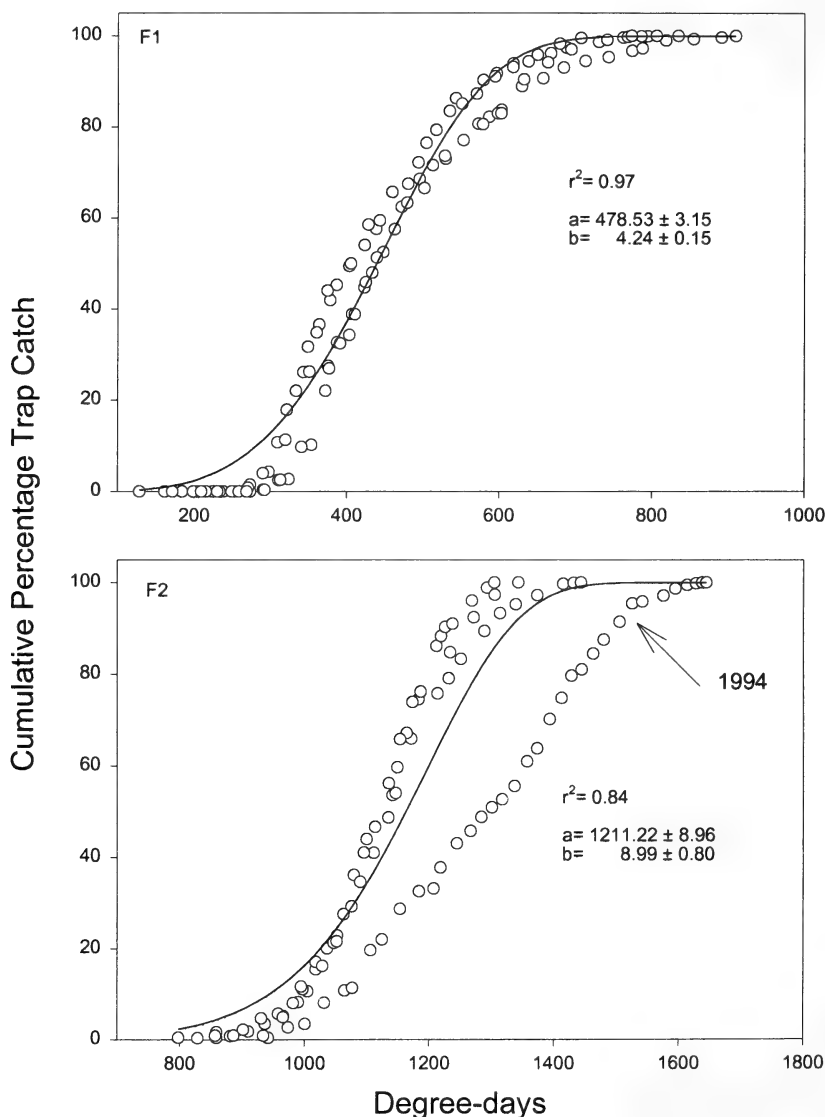


**Figure 3.** Cumulative trap captures of first (F1)- and second (F2)-flight *Choristoneura rosaceana* (o) in pheromone traps in Cawston, 1994-1997 combined, plotted against $°dd_{10°C}$ air temperature after 1 January, compared with curves (solid lines) modelled by Weibull functions with estimated parameters a and b (see text).

period (Fig. 3). The functions of trap catch from the two areas were similar and predicted 50% flight at 438 (Cawston) and 485 (Summerland)$°dd_{10°C}$ after 1 January. Second-flight cumulative trap captures in Cawston were not as accurately described by a Weibull function (Fig. 3), due mainly to a prolonged flight in 1994. First- and second-male flights had similar durations in Cawston, varying from 481-636 and 476-779 $°dd_{10°C}$, respectively.

**Oviposition.** Oviposition commenced $29 \pm 2.2$ $°dd_{10°C}$ (mean $\pm$ SE) after first female eclosion (Fig. 4). Weibull functions predicted 50% oviposition to occur 78, 113, 99 and 91 $°dd_{10°C}$ after first female eclosion for the overwintered generation in 1996, and the overwintered and summer generations in 1997, and for all generations combined, respectively. Duration of the oviposition period is probably best estimated by the overwintered-generation oviposition in 1997, because the adults producing the eggs were collected throughout the eclosion period and not at only one time, as in 1996. The oviposition period for the overwintered generation in 1997 lasted 303 $°dd_{10°C}$ after first female eclosion.
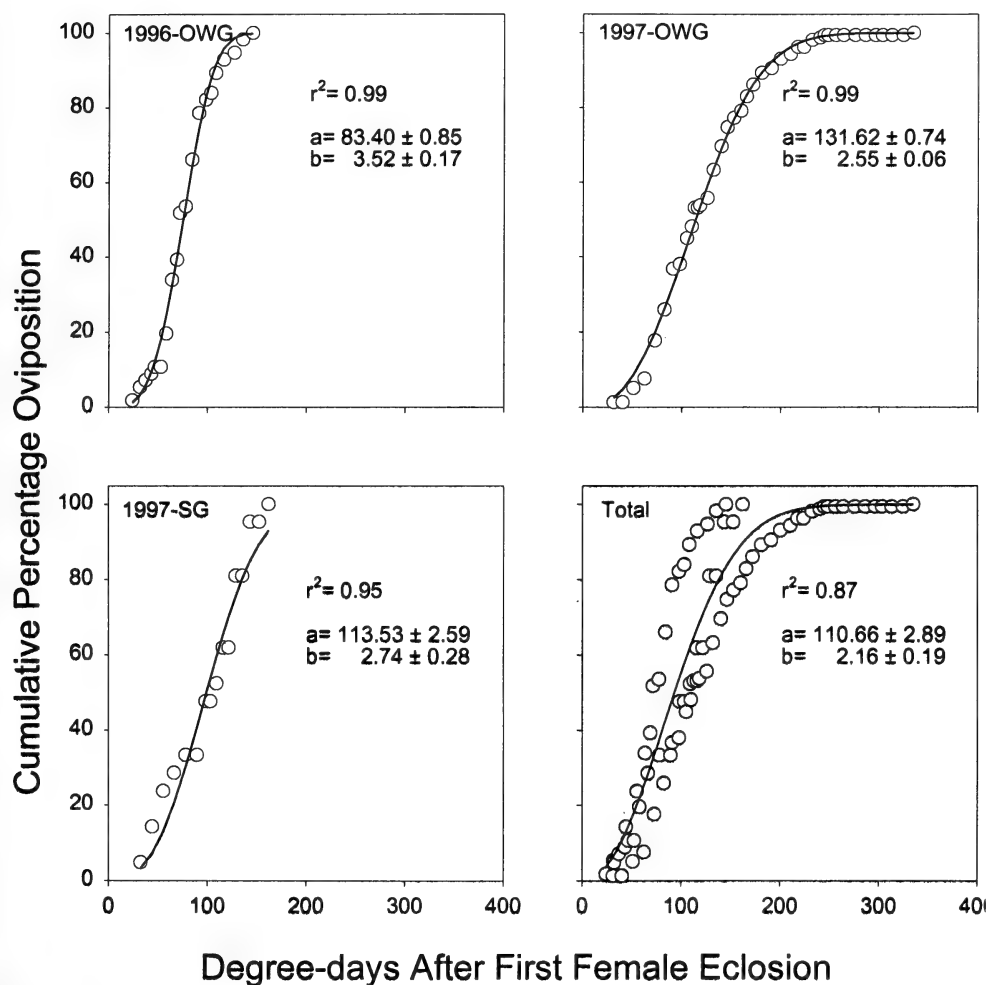


**Figure 4.** Observed cumulative oviposition (o) for overwintered-generation (OWG) *Choristoneura rosaceana* in 1996 and for overwintered (OWG)- and summer (SG)-generations in 1997 plotted against $°dd_{10°C}$ air temperature after first female eclosion, compared with curves (solid lines) modelled by Weibull functions with estimated parameters a and b (see text).

# DISCUSSION

Our finding that eclosion of *C. rosaceana* is protandrous in British Columbia, is consistent with reports elsewhere in its range (Onstad *et al.* 1985; Delisle and Bouchard 1995). Weibull functions did not fit the multiple-year eclosion data for either sex well (Fig. 1), suggesting differences in adult eclosion patterns from year to year. These differences probably arise because the larval collection method varied between years of this study. In 1996, larvae were collected between 87-89 $°dd_{10°C}$ after 1 January, instead of throughout the larval activity period as in 1997. Eclosion percentiles in 1996 always preceded those in 1997 (Table 1), suggesting that larvae that broke diapause late may have been missed in the 1996 sample. Therefore, the 1997 data probably most accurately reflect normal eclosion patterns. The capture of males in pheromone-baited traps prior to the first observed eclosion of collected males may indicate that the active range of the pheromone-baited trap is large enough to attract males from slightly warmer microclimates than the captive larvae had experienced.

The relationships between cumulative percent of trap catch and accumulated $°dd_{10°C}$ in the overwintered generation were similar in the four field seasons in Cawston as well as the two seasons at Summerland (Figs. 2, 3). The first male trap catch at 214-292 $°dd_{10°C}$ after 1 January in the six site-years is slightly later, but comparable to male trap catch in filbert orchards in Oregon (197.8-227 $°dd_{10°C}$ after 1 March) (AliNiazee 1986). Any difference between January and March start dates for $°dd_{10°C}$ accumulation would be negligible as few °dd accumulated between 1 January and 1 March in all four years of our study. The first male captured in the summer-generation flight could only be measured accurately from the Cawston flight data (Fig. 3). The first male captured in pheromone-baited traps, 797-942 $°dd_{10°C}$ after 1 January, was similar to the observed summer generation in filbert orchards in Oregon (838.3-923.8 $°dd_{10°C}$ after 1 March) (AliNiazee 1986). Any delay in initiation of flight in filbert orchards may be due to variation in larval development on different hosts (Onstad *et al.* 1985; Carrière 1992) as filbert is a poor quality host (Delisle and Bouchard 1995) that may cause extended larval development times.

The durations of the first and second flights were similar as indicated by $°dd_{10°C}$ accumulations from first to last moth capture in pheromone-baited traps in Cawston which ranged from: 481-636 $°dd_{10°C}$ and 476-779 $°dd_{10°C}$ for first and second flights, respectively. First flight in filbert orchards in Oregon lasted a similar duration (651 $°dd_{10°C}$) but the second generation was shorter than our findings (288.3 $°dd_{10°C}$) (AliNiazee 1986). Duration of the second flight will vary depending on environmental conditions. For example, constant high temperatures of 32°C may cause development of *C. rosaceana* to slow or cease and temperatures between 28-32°C can induce diapause in *C. rosaceana* larvae despite summer photoperiod conditions (Gangavalli and AliNiazee 1985a, 1985b). High summer temperatures in Oregon prolonged development of the overwintered generation and resulted in a long flight duration (AliNiazee 1986). Low numbers of summer generation adults may be the result of several factors. A late spring eclosion due to cool temperatures could cause first- and second-instar larvae of the summer generation to be exposed to diapause-inducing conditions (short day length, cool temperatures) and cease development. High summer temperatures may also induce summer-generation larvae to enter diapause. Larval hosts can influence diapause induction (Carrière 1992; Hunter and McNeil 1997) and larval development (Onstad *et al.* 1986; Carrière 1992). For example, summer-generation larvae that feed on old apple leaves due to a delay in spring eclosion of overwintering larvae will develop slowly (Onstad *et al.* 1986) and may enter diapause before completing development. A small second flight was observed in 1997 at Summerland, probably because a cool spring delayed adult eclosion, and most summer-generation larvae entered diapause, not emerging until our 1998 collections in spring.

Oviposition started 24, 31 and 33 $°dd_{10°C}$ after first female eclosion in the overwintered

generation in 1996 and the overwintered and summer generations in 1997, respectively (Fig. 4). In comparison, Gangavalli and AliNiazee (1985a) observed a pre-oviposition period of 35.2 $°dd_{11.9°C}$ while Onstad *et al.* (1985) estimated it to be 14 $°dd_{10°C}$. Older studies (Schuh and Mote 1948; Chapman and Lienk 1971) showed that no oviposition occurred within the first 24 h of male-female interaction. Oviposition started approximately 45 $°dd_{10°C}$ after first moth capture and 50% of oviposition was predicted to occur ca. 113 $°dd_{10°C}$ after first female eclosion, approximately 130 $°dd_{10°C}$ after first moth capture. Trap catches can be used as an accurate indicator of adult female eclosion and ovipostion because the first trap catch in both years preceded eclosion of females by a small and consistent margin.

Capture of the first male moth in pheromone-baited traps preceded the first observed eclosion of adult males and females of the overwintering generation by a consistent margin in both 1996 and 1997, and therefore could be used as a reliable indicator of adult eclosion (Table 1). Pheromone dispensers, for the purposes of mating disruption, could be positioned in the orchard immediately after biofix and could disrupt mating of even the earliest eclosing females. Pheromone dispensers should release enough pheromone to disrupt adult mate-finding behaviour throughout both flight periods, until early October, as the size of the summer generation is difficult to predict. Alternatively, growers may be able to disrupt the adults that emerge from the overwintered generation and add additional dispensers later in the season if conditions indicate a large second generation. If the second approach is taken, pheromone dispensers to disrupt the first generation should be effective throughout the first oviposition period. Direct correlations between biofix and developmental stages of *C. rosaceana* were not obtained in this study, and should be conducted before recommendations of mating disruption of the overwintering generation alone are made.

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# Two new species of Arctiidae (Lepidoptera) from the Yukon Territory, Canada[1]

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## ABSTRACT

*Arctia brachyptera* sp. n. and *Dodia verticalis* sp. n. are described from the Yukon Territory, Canada, and *Arctia caja opulenta* is elevated to species rank. Illustrations of the adults and female genitalia are provided.

## INTRODUCTION

For reasons that are not clear, most of the arctic Arctiidae are extremely rare. For example, only two nearctic specimens of *Hyperborea czekanowskii* Grum-Grshimailo (Ferguson, 1985) and two specimens of *Neoarctia lafontainei* Ferguson, have been collected. With the exception of *Grammia quenseli* (Paykull) and *Acsala anomala* Benjamin, most other arctic species are known from fewer than a dozen nearctic specimens. Most of these species are holarctic and are equally rare in the Palearctic. Here we elevate *Arctia caja opulenta* (Hy. Edwards) to species status and describe one new *Arctia* Schrank and one new *Dodia* Dyar.

## *Arctia opulenta* (Hy. Edwards) rev. stat.

(Figures 1c, 2c)
*Euprepia opulenta* Hy. Edwards, 1881: 38
*Arctia caja* ssp. *americana*
  a) *phaeosoma* (Butler), Ab. *opulenta* (Hampson, 1901:464).
*Arctia caia opulenta* (Hy. Edwards), Dyar, 1902:92.
*Arctia caja opulenta* (Hy. Edwards), McDunnough, 1938:53; Hodges *et al*.117

*Arctia opulenta* differs from *A. caja* (L.) by its smaller size (forewing length 25 mm), its small, ellipsoidal eyes and diurnal flight vs. larger size (forewing length 32 mm), large, orbicular eyes and nocturnal flight. Also, the posterior portion of the corpus bursae of female *A. caja* narrows toward the ductus bursae (Figure 2a) but the posterior corpus bursae of *A. opulenta* is swollen to about the same size as the anterior corpus bursae and separated from it by a slight constriction (Figure 2c). In *A. caja* the appendix bursae is smooth, C- shaped, and bends from the side of the posterior corpus bursae across the dorsal side of the ductus bursae and around, almost to the dorsal corpus bursae; the ductus seminalis arises from the tip of the appendix bursae, from which a large, sausage-like diverticulum extends anteriorly, almost to the anterior end of the corpus bursae. In *A. opulenta* the appendix bursae is smooth-walled like that of *A. caja* (deeply furrowed in *A. brachyptera*) but much shorter, terminating on the dorsal side of the

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[1]Mailed January 2000

ductus bursae. As in *A. caja*, the ductus seminalis arises from the tip of the appendix bursae and has a large, sausage-like diverticulum; however, this diverticulum is much smaller than that of *A. caja*, closely approaching the appendix bursae in size and shape. Externally, the ovipositor lobes of *A. opulenta* are deeply notched and those of *A. caja* are bluntly pointed.

It is clear why Hampson (1901) listed A. opulenta as an aberration. The white area of the forewing and red area of the hindwing of the holotype are greatly increased, leaving only submarginal rows of brown and black spots respectively.

*Arctia opulenta* has been collected in arctic, alpine and subarctic habitats from Alaska, east to Manitoba.

## *Arctia brachyptera* Troubridge and Lafontaine **sp. n.**

(Figures 1a, 1b, 2b)

**Type material.** Holotype female: Canada, Yukon, Nickel Creek, 4500'. St. Elias Range, 24-25 June 1991. J. Troubridge, in the Canadian National Collection, Ottawa. Paratypes: 1 female, same data as holotype; 1 female,YT, Mt Archibald, 6500', St. Elias Range, 26 June 1991, J. Troubridge.

**Description.** Female. Forewing length 18 mm. Head, palpi, and scape mouse brown; antennae pectinate; eye reduced, ellipsoidal, length to width ratio 1.6:1; haustellum reduced. Prothoracic collar mouse brown, thinly edged basally with red and then white scales. Thorax mouse brown, with off-white scales in anterior tegulae. Abdomen mouse brown, tergites edged antero-laterally with pinkish orange scales. Dorsal forewing mouse brown, adbasal, basal, medial, postmedial, and subterminal lines off white, variable in width, and may be reduced or absent (Figures 1a, 1b); fringe medium gray, checkered with dark gray between veins. Dorsal hindwing pinkish orange (Figure 1b) to pinkish brown (Figure 1a); subterminal black spots may fuse to form black band; postmedial black spot across discal cell; antemedial band black.

**Male genitalia.** Unknown.

**Female genitalia.** Ovipositor lobes notched apically, covered with setae; ductus bursae heavily sclerotized; corpus bursae bulbous, furrowed anteriorly with two minute dorsal signa, posterior half very deeply furrowed, from which the irregular, deeply furrowed appendix bursae arises; appendix bursae gives rise to ductus seminalis; ductus seminalis with large, oblong diverticulum arising near juncture with appendix bursae; diverticulum swollen, resembling a second corpus bursae.

**Diagnosis.** This species cannot be confused with any other species in western North America. The closely related *A. opulenta* (Figure 1c) occurs with *A. brachyptera* in the St. Elias Mts., YT, and *A. caja* (Figure 1d) occurs farther to the south in more temperate habitats. The females of these species can easily be separated by their wing size - those of *A. opulenta* and *A. caja* are of normal size, and those of *A. brachyptera* are reduced, leaving the females, at least when carrying a full egg-load, flightless. In addition, the abdomen of *A. brachyptera* is brown with the tergites edged anterolaterally with pinkish-orange scales, while those of *A. opulenta* and *A. caja* are reddish orange with large black spots centrally located on the tergites. Also, the black hindwing spots on *A. brachyptera* do not have the blue sheen present in *A. opulenta* and *A. caja*. The eyes of *A. caja* are large and orbicular, indicating nocturnal flight, but those of *A. brachyptera* and *A. opulenta* are small and ellipsoidal, indicating diurnal habits. Internally, the posterior corpus bursae of *A. brachyptera* is much narrower than that of the other two species and the appendix bursae is short and deeply furrowed in *A. brachyptera* but long, sausage-like, and smooth in the other two species. The ovipositor lobes of *A. brachyptera* are notched apically but not as deeply notched as in *A. opulenta*. Those of *A. caja* are bluntly pointed. The male, when found, should have fully developed wings and have wing and abdominal markings similar to those of the female.

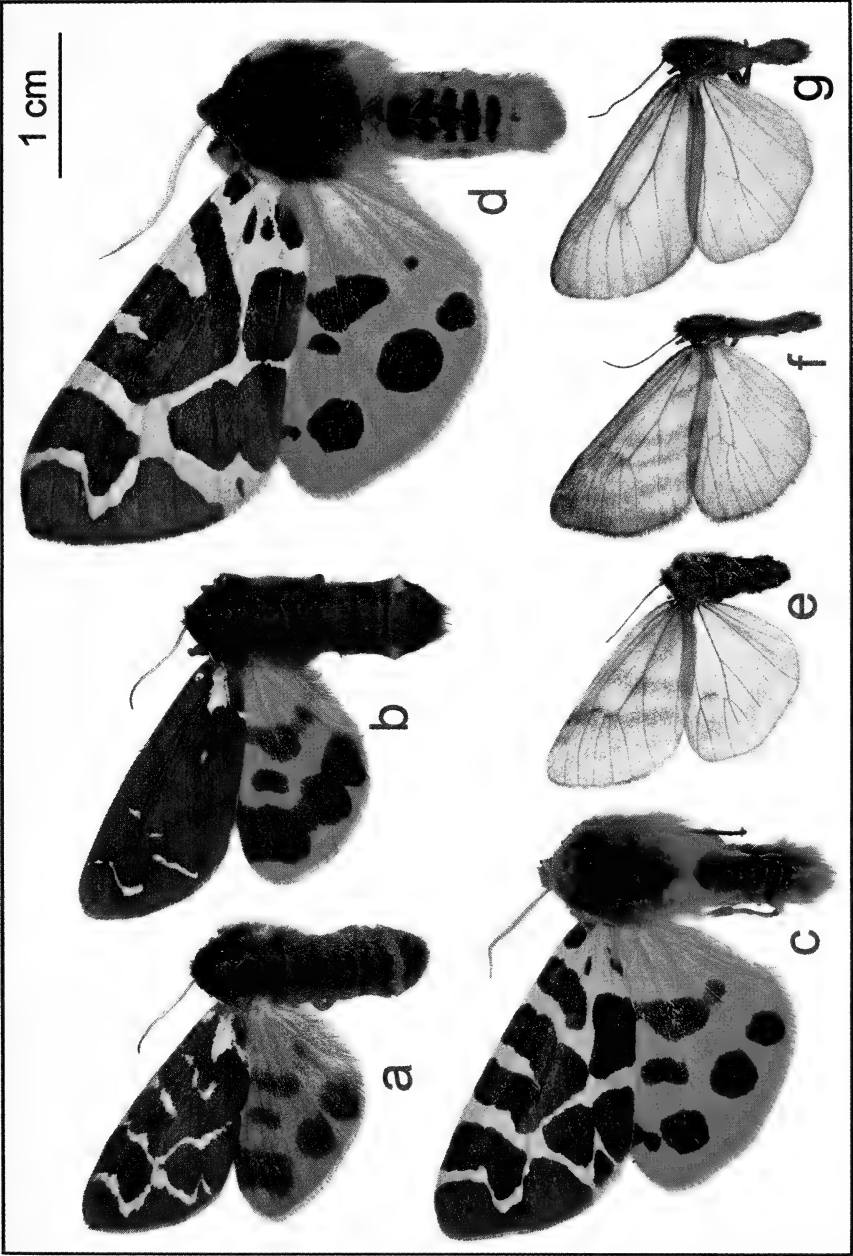**Derivation of the name.** The name *brachyptera* refers to the reduced wing size of the female.

**Figure 1.** Adult females of: **a)** *Arctia brachyptera* (paratype), Mt Archibald, St. Elias Mts., YT; **b)** *Arctia brachyptera* (paratype), Nickel Creek, St. Elias Mts., YT; **c)** *Arctia opulenta*, Mt Archibald, St. Elias Mts.,YT; **d)** *Arctia caja*, Oyster R., BC; **e)** *Dodia verticalis* (holotype), British Mts., YT; **f)** *Dodia albertae*, Nickel Creek, St. Elias Mts., YT; **g)** *Dodia kononenkoi*, Richardson Mts., YT.

**Distribution and Habitat**. All three known specimens of *A. brachyptera* were collected in late June on dry tundra hilltops in the St. Elias Mts., YT. A single larva of *A. opulenta* was collected at the same time but at a lower elevation in wet shrub tundra.

## *Dodia verticalis* Lafontaine and Troubridge **sp. nov**.

(Figures 1e, 2d,)

**Type Material**.  Holotype female: Canada, Yukon Territory, British Mts., 69°17'N 140°03'W, 24 VI 1984, G. & M. Wood & D. Lafontaine, in the Canadian National Collection. Paratype: 1 female, Yukon, Km 406, Dempster Hwy., 20 June 1987, Jim Troubridge.

**Description**. Female. Forewing length 15 mm.  Head covered in hair-like gray-brown scales; antennae filiform, black ventrally, covered with white and gray-brown scales dorsally; scape gray brown; eye reduced, oval; haustellum short but typical for genus; palpi very small but typical for genus. Prothoracic collar, tegulae, and thorax covered with hair-like gray-brown scales. Abdomen stout, light gray brown. Wings sparsely covered with narrow scales. Dorsal forewing very pale gray with darker gray brown, diffuse, broad, basal, antemedial, and postmedial lines arising perpendicular to posterior margin, bending to become perpendicular to costal margin at cubitus; subterminal row of diffuse, gray-brown spots between veins; fringe light gray. Dorsal hindwing very pale gray with obscure, gray-brown subterminal band; submarginal band whitish; fringe light gray; discal lunule gray brown.

**Male genitalia**. Unknown.

**Female genitalia.** Ovipositor lobes rounded, covered with setae, with dorsolateral pits at base; ductus bursae lightly sclerotized, relatively short; corpus bursae bulbous, thin-walled, with two small dorsal signa, corpus bursae posterioris narrows, widely attached to smaller appendix bursae at ductus bursae; left appendix bursae gives rise to ductus seminalis; ductus seminalis with large, bulbous diverticulum arising near juncture with appendix bursae - this diverticulum swollen so as to resemble a second corpus bursae but very thin-walled and delicate; anterior apophyses present and well developed; posterior apophyses short.

**Derivation of the name**. The name *verticalis* refers to the ordinary lines of the dorsal forewing, which arise perpendicular to the posterior margin. Those of *D. albertae* Dyar run more or less parallel with the outer margin.

**Diagnosis.**  Dr. Vladimir Dubatolov has compared a photograph of *D. verticalis* with the *D. sazovovi* Dubatolov types from the Altai Mts. The wing markings of female *D. verticalis* are similar to those of male *D. sazovovi*, but the females of *D. sazovovi* are flightless (forewing length 5 mm) (V.V. Dubatolov, pers. comm.). In the Nearctic, *D. verticalis* flies with *D. albertae* (Figure 1f) and *D. kononenkoi* Tshistjakov and Lafontaine (Figure 1g). The wings of *D. albertae* are more heavily scaled than those of *D. verticalis* and the body is thinner and more delicate in *D. albertae* than *D. verticalis*. The ordinary lines of the dorsal forewing of *D. verticalis* arise perpendicular to the posterior margin, but those of *D. albertae* run more or less parallel with the outer margin. The wings of *D. kononenkoi* are slate gray and unmarked, but those of *D. verticalis* are paler with faint but noticeable bands.  Judging by the stout body of *D. verticalis*, we feel that it is more closely related to the *D. kononenkoi-transbaikalensis* Tshistjakov group than the *Dodia albertae-D. diaphana* (Eversmann) group, whose members have a more slender bodies. The vertical lines on the forewing of *D. verticalis* are considerably more obvious on fresh specimens than on dried material. The scales probably shrivel up when they dry, making the wings even more translucent than they were originally. Adults and genitalia of the other Nearctic species of *Dodia* were illustrated by Tshistjakov and Lafontaine (1984).

**Distribution and habitat**. *Dodia verticalis* has been found on dry tundra hillsides in the Richardson and British Mts., YT. It flies in mid to late June.

## ACKNOWLEDGEMENTS

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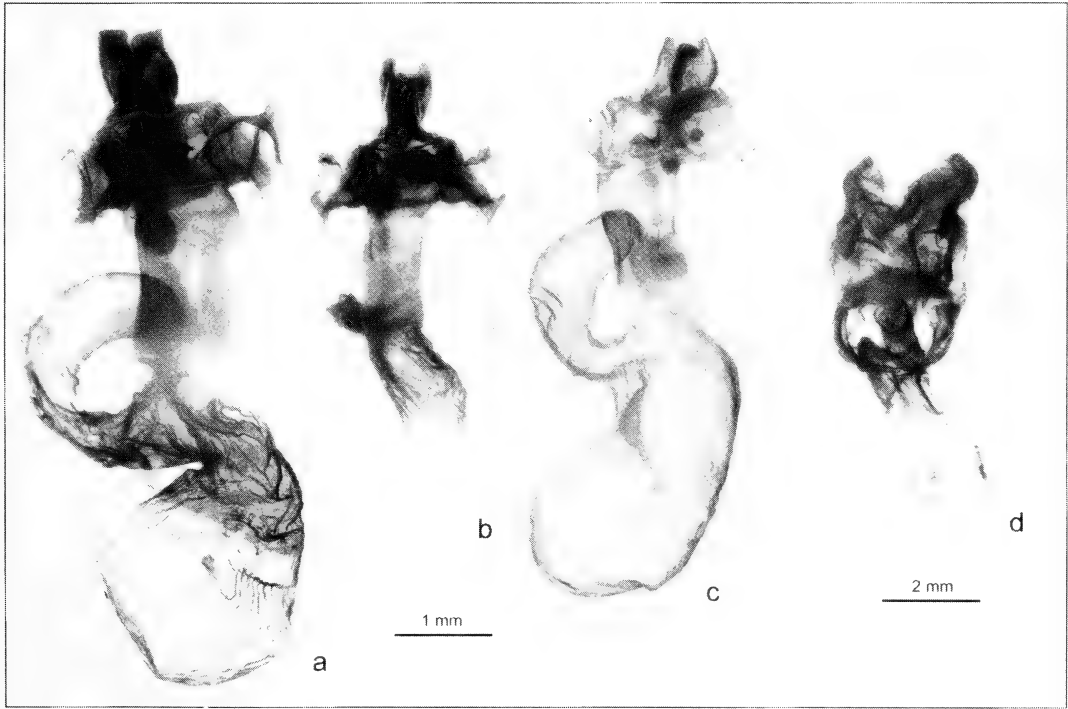


**Figure 2.** Female genitalia of : **a)** *Arctia caja*; **b)** *Arctia brachyptera* (paratype); **c)** *Arctia opulenta*; **d)** *Dodia verticalis* (holotype).

# Effect of mating disruption dispenser placement on trap performance for monitoring codling moth (Lepidoptera: Tortricidae)

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## ABSTRACT

Capture of codling moth, *Cydia pomonella* L., in lure-baited, wing-style traps placed at varying distances from polyethylene dispensers (Isomate-C+) in the canopy of an apple orchard was investigated during 1997. Replicated studies of trap - dispenser position were conducted with releases of sterile moths around each trap. In the first experiment, moth catch was unexpectedly higher in traps placed 1 m below the 1997 dispenser's height (3.38 m) compared with traps at the dispenser's height. No differences were found in moth catch for traps placed adjacent to or 1 and 2 m distant from dispensers at the dispenser height. Subsequent analysis of the Isomate-C+ dispensers left in the field from 1996 found that they continued to emit low levels of sex pheromone through July. In the second experiment, the 1996 dispensers were removed from the trees around each trap and moth catch was significantly lower in traps placed 1 m below the 1997 dispenser height and in traps adjacent to the dispenser compared with traps 1 and 2 m distant at the dispenser's height. In a third test, moth catches were significantly reduced when the trap - dispenser distance was $\leq 0.3$ m for both 1996 and 1997 dispensers. Moth catch did not vary in traps placed 0.3 to 2.0 m from either dispenser type. A *post-hoc* evaluation of trap placements used in an areawide project situated near Oroville, Washington, in 1996 found that 9% of traps were placed within 0.3 m of dispensers. This percentage of traps increased to 30% in 1997 following recommendations that traps should be placed higher in the canopy.

**Key words**: codling moth, sex pheromone, mating disruption, apple, lures, traps

## INTRODUCTION

Traps baited with codlemone, the main sex pheromone component of codling moth, *Cydia pomonella* L., (Roelofs *et al.* 1971) have been used for 25 years to monitor populations in tree-fruit orchards (Butt *et al.* 1974; Maitlen *et al.* 1976). Codling moth catch in codlemone-baited traps has been used to establish action thresholds (Madsen and Vakenti 1972; Riedl and Croft 1974; Madsen *et al.* 1974) and as an indicator of codling moth phenology (Riedl *et al.* 1976; Beers and Brunner 1992). Codling moth catch in traps is also used to evaluate the success of mating disruption in orchards treated with sex pheromone (Vickers and Rothschild 1991).

The efficacy of numerous trap and lure types has been evaluated for codling moth (earlier work summarized in Riedl *et al.* 1986; Knodel and Agnello 1990; Vincent *et al.* 1990; Kehat *et al.* 1994). A synthesis of this work led to a standardization in the use of traps and lures, including placement of the trap within the canopy (Riedl *et al.* 1986). Codling moth adults are active in the upper canopy of trees (Borden 1931; Weissling and Knight 1995) and traps placed high in the canopy catch more moths than traps placed low in the canopy (Riedl *et al.* 1979; Ahmad and Al-

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Gharbawi 1986; Barrett 1995; Knight 1995a) or outside the canopy (Howell *et al.* 1990; Mani *et al.* 1995). Consideration of trap placement can also include the trap's orientation with wind direction, tree quadrant, and position with relation to the canopy's perimeter (Riedl *et al.* 1979; McNally and Barnes 1981). The importance of trap position within an orchard, e.g. traps on the edge versus internal traps, has also been evaluated (Westigard and Graves 1976).

Standardization of trap use in orchards using mating disruption is of critical importance in monitoring codling moth. The occurrence of 'false negatives' (absence of trapped moths despite the occurrence of fruit injury) has been particularly problematic in such orchards, especially in orchards monitored with lures loaded with 1 mg of codlemone (Knight 1995b; Gut and Brunner 1996). Higher moth catches have been generated by using lures with higher pheromone loads (Charmillot 1990; Knight 1995a; Gut and Brunner 1996; Judd *et al.* 1996) and by placing traps in the upper third of the canopy (Riedl *et al.* 1986; Barrett 1995; Knight 1995a; Gut and Brunner 1996). One factor that has not been considered in formulating recommendations for codling moth trap placement in orchards using mating disruption is the proximity of dispensers and traps. Herein, we report studies examining the effect of dispenser and trap placement and proximity on codling moth trap performance.

## MATERIALS AND METHODS

Studies were conducted in a 20-ha apple orchard (mixed planting of 'Red Delicious' and 'Golden Delicious'), situated near Moxee, WA in 1997. Tree height (±SE) averaged 3.99 (0.06) m (n = 160). Isomate C+ dispensers (Pacific Biocontrol, Vancouver, WA) were attached to branches using plastic clips. Dispensers for 1996 and 1997 were attached with different colored clips: blue in 1996; red in 1997. Two dispensers were placed in the upper canopy of each tree at a rate of 1,000 dispensers per ha each year. Dispensers were applied on 21 April in 1996 and 23 April 1997. Dispenser application height (±SE) averaged 3.38 (0.05) m (n = 160) and was similar both years. In many instances, dispensers in 1997 were clipped adjacent to dispensers from 1996. Dispensers were loaded with 220 mg of a three-component sex pheromone blend (62:31:7%) of 8,10-dodecadien-1-ol (93% EE [codlemone], 3.8% EZ, 2.6% ZE, 0.6% ZZ), 1-dodecanol, and 1-tetradecanol; and 13% inert ingredients (UV inhibitors and antioxidants). The residual content of 1996 dispensers (n = 14) were analyzed by our laboratory on several dates in 1997 with gas chromatography. Dispensers were cut into 2 cm pieces and rinsed continuously with dichloromethane for 3 hours. Samples were processed with a HP7673 automatic sampler and a Series II 5890 gas chromatograph using a 60 m x 0.32 mm capillary column coated with dimethylpolysiloxane. Samples were injected in splitless mode with 40°C initial temperature for 6 min., a ramp rate of 25°C per min., and a final temperature of 300°C for 10 min. Undecanol was used as the internal standard. Recovery rates for each pheromone component were > 90%. Dispensers (n = 5) placed in the orchard in 1997 were analyzed biweekly by Scenturion Inc. (Clinton, WA). These data were provided by Pacific Biocontrol (Vancouver, WA).

Wing-style traps with IC sticky liners (Trece Inc., Salinas, CA) were placed every 50 m in the orchard and baited with a red septa loaded with 10 mg of codlemone (Trece Inc., Salinas, CA). In experiment 1, traps were placed at approximately the same height or 1.0 m lower than 1997 dispensers (red clip); and either adjacent, 1.0, or 2.0 m distant from dispensers; five positions replicated six times. Dispenser - trap distances were measured from the dispenser to the mid-point on the outside of the trap. Experiment 1 was run from 7 to 14 June, 1997. In experiment 2, traps were placed on 14 June on different trees but in the same relative positions as experiment 1; five positions replicated eight times. However, all the 1996 dispensers (blue clips) were removed from the test trees and the two adjoining trees within each row prior to the start of this experiment. In experiment 3, codlemone-baited traps were placed on new trees at 0.15, 0.30, 0.61, 1.0, and 2.0 m from either a 1996 or a 1997 dispenser; ten positions replicated nine times.

In addition, to demonstrate whether either dispenser was attractive to moths, similar traps were baited with either 1996 or 1997 dispensers. These traps were placed at 3.38 m height and all other dispensers within 3 m of each trap were removed. Five replicates of each treatment were run from 16 to 18 June, 1997, and four replicates were run from 19 to 24 June, 1997.

At the start of each experiment, 300 sterile, unsexed moths were released around each trap by tapping chilled moths out of petri plates onto both the tree and the ground. Sterile codling moths of both sexes were obtained from the codling moth mass-rearing SIR facility in Osoyoos, British Columbia. Moths were sterilized with gamma radiation (33 krad) from a Cobalt[60] source (dose rate of 1,150-1,320 rad/min) and held at 0 to 2°C before field release. All experiments used a randomized complete block design. Numbers of moths caught per trap were analyzed with analysis of variance (ANOVA) and means were separated with Fisher's LSD (Hintze 1987). The analyses were repeated on transformed data (log(x+1.)) with the same results; results based on untransformed data are presented. Moth catch in experiment 3 was analyzed as moths caught per trap per day. A two-way ANOVA was used to examine the effects of dispenser age and trap - dispenser distance. Due to a significant interaction between these factors ($P < 0.05$) separate ANOVA's were run for each year and between the two dispenser ages at each distance.

An evaluation of grower's placement of dispensers and traps to monitor codling moth in orchards using mating disruption was conducted within the U.S.D.A. areawide codling moth management program situated in the U. S. near Lake Osoyoos and adjacent with the Canadian border. Dispenser and trap height and the distance between traps and new dispensers were measured for all traps in this 150-ha site from 1995 to 1997. ANOVA's were run for each factor among the 3 years. Means were separated with Fisher's LSD.

# RESULTS

**Experiment 1**. Significant differences were found in moth catch based on the relative trap and dispenser position in the canopy ($F = 3.2$; df = 4, 25; $P = 0.03$: Table 1). Moth catch was significantly higher in traps placed 1 m below the dispensers than in all traps placed 10 - 30 cm above the dispenser height. No difference in moth catch occurred in traps placed adjacent to the dispenser and traps placed 1 or 2 m away at the same height.

**Table 1**

Mean number of codling moths caught in 10 mg lure-baited traps placed at several positions in the canopy in relation to 1997 Isomate-C+ dispensers. Dispensers were applied on 23 April, 1997 and the test was conducted from 7 to 14 June, 1997.

| Treatment | Trap position in relation to: | | Mean no. of moths caught per trap(±SE) |
|---|---|---|---|
| | Position of dispenser[1] | Distance from dispenser[2] | |
| 1 | Same height | Adjacent | 5.2 (1.7)bc |
| 2 | Same height | 1 m | 5.5 (2.3)bc |
| 3 | Same height | 2 m | 4.8 (1.1)c |
| 4 | 1 m below | 1 m | 12.7 (2.6)a |
| 5 | 1 m below | 2 m | 11.2 (2.3)a |

Column means followed by a different letter are significantly different, $P < 0.05$, Fisher's LSD
[1] Trap heights (±SE) were on average 0.10 (0.02), 0.19 (0.03), and 0.26 (0.06) m above dispensers in treatments 1 - 3, respectively. Trap heights (±SE) were on average 1.03 (0.06) m and 1.07 (0.08) m below dispensers in treatments 4 and 5, respectively.
   [2] Trap distance (±SE) from the nearest 1997 dispenser averaged 0.18 (0.03) in treatment 1; 1.07 (0.10) m and 1.24 (0.12) m in treatments 2 and 4, respectively; and 2.16 (0.08) m and 2.23 (0.18) m in treatments 3 and 5, respectively.

**Analysis of dispensers**. Dispensers placed in the field in April 1996 still contained and released codlemone through July, 1997 (Table 2). The mean daily loss of codlemone from the 1996 dispenser during June and July averaged 0.15 mg. The purity of the EE8,10-12:OH isomer in these samples ranged from 78 - 89%. In comparison dispensers applied in 1997 had much higher release rates (0.6 mg codlemone per d) and a higher purity, 91-93% (Table 2).

## Table 2
Residual content (±SE), isomeric purity and mean daily loss of E8,E10-12:OH from Isomate-C+ dispensers applied on 21 April, 1996, and 23 April, 1997, and sampled from June to July, 1997.

| | 1996 Dispensers | | |
| Date | Residual (mg) 8,10-12:OH | % EE8,10-12:OH | Mean loss (mg per d) EE8,10-12:OH |
| --- | --- | --- | --- |
| 01 June | 10.1 (2.2) | 88.8 | - |
| 26 June | 6.3 (1.3) | 77.5 | 0.15 |
| 04 July | 5.3 (1.8) | 84.0 | 0.13 |
| 31 July | 0.8 (0.3) | 79.4 | 0.17 |

| | 1997 Dispensers | | |
| Date | Residual (mg) 8,10-12:OH | % EE8,10-12:OH | Mean loss (mg per d) EE8,10-12:OH |
| --- | --- | --- | --- |
| 5 June | 103.0 (0.6) | 93.0 | - |
| 19 June | 95.9 (1.7) | 92.1 | 0.53 |
| 17 July | 75.4 (1.0) | 91.3 | 0.70 |
| 31 July | 65.5 (1.4) | 92.8 | 0.57 |

## Table 3
Mean number of codling moth caught in 10 mg lure-baited traps placed at several positions in relation to 1997 Isomate-C+ dispensers following the removal of 1996 dispensers on 14 June, 1997. Test was conducted from 14 to 21 June, 1997.

| | Trap position in relation to: | | Mean no. of moths |
| Treatment | Position of dispenser[1] | Distance from dispenser[2] | caught per trap(±SE) |
| --- | --- | --- | --- |
| 1 | Same height | Adjacent | 7.1 (3.6)c |
| 2 | Same height | 1 m | 29.8 (3.9)ab |
| 3 | Same height | 2 m | 34.0 (5.9)a |
| 4 | 1 m below | 1 m | 19.1 (4.6)bc |
| 5 | 1 m below | 2 m | 18.8 (6.5)bc |

Column means followed by a different letter are significantly different, $P < 0.05$, Fisher's LSD
[1] Trap height (±SE) were on average 0.08 (0.02), 0.14 (0.10), and 0.07 (0.06) m above dispensers in treatments 1 to 3, respectively. Trap heights (±SE) were on average 1.01 (0.06) and 0.98 (0.07) m below dispensers in treatments 4 and 5, respectively.
[2] Trap distance (±SE) from the nearest 1997 dispenser averaged 0.15 (0.03) in treatment 1; 1.18 (0.08) and 1.20 (0.13) m in treatments 2 and 4, respectively; and 2.04 (0.08) and 2.03 (0.15) m in treatments 3 and 5, respectively.

**Experiment 2**. Moth catch was significantly affected by the relative positions of the trap and dispensers following the removal of the 1996 dispensers from the test and adjoining trees ($F = 4.4$; df = 4, 35; $P < 0.01$: Table 3). Similar to experiment 1, trap height was a significant factor affecting moth catch ($F = 5.8$; df = 1, 28; $P = 0.02$), but in contrast to the earlier test (Table 1), moth catch was higher in traps positioned higher in the canopy (Table 3). Moth catch was significantly lower in traps 0.15 m from dispensers compared with traps at 1 and 2 m distant at the same height. No significant difference in moth catch was found across both trap heights for

traps placed 1 or 2 m from dispensers ($F = 0.1$; df = 1, 28; $P = 0.71$).

**Experiment 3**. Significant differences in moth catch occurred as a function of trap distance to both 1996 and 1997 dispensers (1996: $F = 4.2$; df = 4, 40; $P < 0.01$; 1997: $F = 12.4$; df = 4, 40; $P < 0.001$) (Table 4). Moth catch was significantly lower when the trap was placed $\leq 0.3$ m than at 1.0 to 2.0 m from a 1996 dispenser. The effect of the 1997 dispenser on trap catch was more pronounced than with the 1996 dispenser. Moth catch was significantly lower at 0.15 m than at all other distances (0.3 - 2.0 m); and moth catch was significantly lower at 0.3 m than from 0.6 to 2.0 m. The effect of dispenser age on moth catch across all dispenser - trap distances was only significantly different at 0.15 m ($F = 12.2$; df = 1, 16; $P < 0.01$).

Traps baited with either 1996 or 1997 dispensers caught moths, mean catch (±SE) per trap per day was 1.52 (0.47) and 0.72 (0.20), respectively. However, moth catch did not differ significantly between dispenser type ($F = 2.5$; df = 1, 16; $P = 0.13$).

**Table 4**

Mean (±SE) daily moth capture in wing-style sticky traps baited with a red septa loaded with 10 mg codlemone placed in an apple orchard treated with Isomate-C+ dispensers (1,000 per ha) in both 1996 and 1997. The test was conducted from 21 to 23 June and 28 June to 4 July, 1997.

| Avg. distance (m) between | Moth capture per trap per day | |
|---|---|---|
| trap and dispensers | 1996 Dispensers | 1997 Dispensers |
| 0.15 | 5.34 (0.66)aA | 2.30 (0.57)aB |
| 0.30 | 5.89 (0.90)abA | 6.11 (1.01)bA |
| 0.60 | 6.37 (0.57)abA | 8.68 (0.96)cA |
| 1.0 | 7.82 (0.64)bcA | 8.50 (0.73)cA |
| 2.0 | 9.22 (1.01)cA | 9.22 (0.73)cA |

Column means followed by different lower case letters and row means followed by different upper case letters are significantly different, P < 0.05, Fisher's LSD.

**Table 5**

Summary of mean (±SE) tree, trap, and dispenser heights (m) and distance (m) between trap and dispensers, and percentages of traps at varying distances from dispensers for the Lake Osoyoos codling moth areawide project from 1995 to 1997.

| | 1995 | 1996 | 1997 |
|---|---|---|---|
| No. of traps | 114 | 167 | 152 |
| Tree height (m) | 3.31 (0.04)a | 3.26 (0.05)a | 3.25 (0.05)a |
| Dispenser height (m) | 2.88 (0.07)a | 2.94 (0.05)a | 2.94 (0.05)a |
| Trap height (m) | 2.68 (0.03)a | 2.46 (0.04)b | 2.89 (0.03)c |
| Trap - dispenser distance (m) | N.A. | 1.72 (0.09)b | 0.93 (0.08)a |
| % traps at each distance | | | |
| class (m) from dispensers | | | |
| $\leq 0.15$ | - | 2.4 | 10.5 |
| $>0.15 < 0.30$ | - | 6.7 | 20.4 |
| $> 0.30 < 1.00$ | - | 8.4 | 18.4 |
| $> 1.00 < 2.00$ | - | 9.6 | 21.7 |
| $> 2.00$ | - | 72.9 | 28.9 |

Means within rows followed by different letters are significantly different, $P < 0.05$, Fisher's LSD.

**Lake Osoyoos Areawide Program**. Dispenser height and the height of the tree where dispensers were hung did not vary during the 3 years of the Lake Osoyoos areawide project

(dispenser height: $F = 0.47$; df = 2, 430; $P = 0.62$; tree height: $F = 0.421$; df = 2, 430; $P = 0.67$). On average, dispensers were placed 0.31 to 0.42 m below the tops of the tree canopy (Table 5). However, trap height varied significantly each year during the 3-year project ($F = 52.39$; df = 2, 430; $P < 0.0001$). Traps were placed on average the highest in 1997 (Table 5). The mean distance between traps and dispensers varied from 1996 to 1997 ($t = 5.92$, df = 317, $P < 0.01$). In association with the higher trap height in 1997 versus 1996, the mean distance between traps and dispensers decreased 0.8 m (Table 5). The percentage of traps placed $\leq 0.3$ m from dispensers increased from 9.1 to 30.9% from 1996 to 1997.

# DISCUSSION

A prerequisite in using codlemone-baited traps to establish action thresholds for codling moth is the standardization of all facets of trap use. Factors that have been well studied include trap and dispenser maintenance and trap placement in the canopy (Riedl *et al.* 1986). Our data show that the proximity of mating disruption dispensers and traps is another significant factor affecting moth catch. Our data demonstrate that placing monitoring traps too close to dispensers, even year-old dispensers, can reduce moth catches. This effect could reduce the effectiveness of traps in detecting populations and predicting crop damage at harvest. Our evaluation of trap and dispenser positioning in growers' orchards showed that the performance of a significant percentage of these traps was likely affected by this factor (Table 5).

Guidelines for placement of traps and dispensers for codling moth in sex pheromone-treated orchards has evolved over the past 25 years. Early studies in Europe and Australia placed both dispensers and traps at a mid-canopy height (Charmillot 1990; Vickers and Rothschild 1991). Weissling and Knight (1995) showed that mating disruption of tethered codling moths was improved when Isomate-C dispensers were placed < 1.0 m from the top of the canopy instead of in mid-canopy. Since 1991, most researchers in the United States testing mating disruption products for codling moth have placed dispensers in the upper third of the canopy while traps were placed at mid-canopy (1.5 - 2.0 m height) (Barnes *et al.* 1992; Pfeiffer *et al.* 1993; Knight 1995b; Trimble 1995; Judd *et al.* 1997). Recent guidelines, however, have recommended that traps be placed, similarly to dispensers, in the upper portion of the canopy to better track codling moth's phenology and to improve detection of local infestations (Barrett 1995; Gut and Brunner 1996). This evolution in the placement of traps and dispensers was reflected in the Lake Osoyoos areawide program from 1995 to 1997 (Table 5). Clearly, placing traps and dispensers at a similar height in the canopy minimizes their separation and increases the likelihood for interference. In addition, the number of sites available in the canopy decreases with increased placement height in pyramidal-shaped canopies.

It is remarkable that the mean distance between traps and dispensers was < 1.0 m in the Lake Osoyoos project in 1997 considering that the recommended rate for Isomate C+ dispensers is only 500 - 1,000 per ha or 1- 2 dispensers per tree in a typical orchard. The architecture of the pruned apple tree may create only a small number of points in the canopy suitable for hanging traps and dispensers. Traps and dispensers are commonly fastened to plastic clips and are attached to unobscured branches in the canopy with a 1.0 to 2.0 cm diameter branch radiating out from the main trunk at 45 - 135°. The number of these available sites in the canopy has not been measured, however, it is not uncommon to observe dispensers applied over a 2 - 5 year time period to be clipped to the same branch in the canopy (unpubl. data). However, because the competitive interaction between traps and dispensers occurs only within a short distance ($\leq 0.3$ m), adequate space exists in the canopy of apple orchards, including young or dwarf, high density plantings, to avoid competition between traps and dispensers.

Improvements in the stability and longevity of the newer Isomate-C+ dispenser (Table 2) compared with the original Isomate-C dispenser (McDonough *et al.* 1992) makes the problem

of trap - dispenser competition more acute. For example, the effect on trap performance of leaving the year-old 1996 dispensers in the canopy during experiment 1 appeared to counteract the importance of trap height (Table 1). While, year-old dispensers contained a lower percentage of the EE8,10-12:OH isomer and had only 20-25% of the emission rate of the 1997 dispensers (Table 2), yet remained attractive and competed with traps when they were placed $\leq 0.15$ m apart (Table 4). The influence of these year-old dispensers on mating disruption of codling moth is unclear. Yet, these findings suggest that growers using the Isomate-C+ dispenser for at least two consecutive years have double the number of active dispensers per area releasing pheromone during the first codling moth flight and probably an elevated concentration of codlemone in the orchard environment. We would expect these factors (increase in point source density and atmospheric concentration) to result in higher levels of mating disruption of codling moth in these orchards than in orchards treated for only one year with Isomate-C+ dispensers.

However, the amount of sex pheromone remaining in Isomate-C+ dispensers and the additional level of mating disruption achieved in the following year after their application depends on the accumulation of heat units accumulated during the growing season and the subsequent fall and winter months. For example, daily temperatures in eastern Washington in 1998 were much warmer than in either 1996 or 1997 and Isomate-C+ dispensers in October contained < 10 mg of residual pheromone compared with 30 - 40 mg of pheromone in the two previous years (G. Thayer, personal communication). Therefore, it is likely that the 1998 dispensers provided only a minor contribution to mating disruption in the 1999 season. Nevertheless, the development of recommendations for dispenser density and emission rates for the Isomate-C+ dispenser needs to consider the residual contribution of year-old dispensers.

## ACKNOWLEDGEMENTS

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# Exclusion fences reduce colonization of carrots by the carrot rust fly, *Psila rosae* (Diptera: Psilidae)

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## ABSTRACT

The effectiveness of exclusion fences in preventing the colonization of carrot plantings by the carrot rust fly, *Psila rosae* (F.), was tested in small field plots. Fenced enclosures were surrounded by panels of mesh nylon window screen 120cm high. Control enclosures were left unfenced. Although the number of first generation *P. rosae* adults captured on yellow sticky traps was not significantly different between control and fenced enclosures, the number of second generation adults emerging within enclosures was significantly higher in control enclosures than in fenced enclosures. The percentage of unmarketable carrots, % damaged carrots, % unmarketable yield, % damaged yield, and number of lesions per carrot were all significantly higher in control enclosures than in fenced enclosures. We conclude that exclusion fences impede the colonization of carrot plantings by *P. rosae* and reduce damage to carrots. The results are discussed as they relate to pest management methods for the carrot rust fly.

**Key words:** *Psila rosae*, carrot rust fly, physical control, exclusion fences

## INTRODUCTION

The carrot rust fly, *Psila rosae* (F.), is the most common and injurious insect pest of carrots grown in Europe and North America (Dufault and Coaker 1987). To control this pest, commercial growers normally apply insecticides throughout the growing season. In British Columbia (BC), up to nine sprays per field have been reported per season (Judd *et al.* 1985), and up to seven sprays per season have been reported in Ontario (Stevenson 1981). Similar spray regimes in Europe often result in less than adequate control (Esbjerg *et al.* 1983). Although population-monitoring-based integrated pest management programs have dramatically reduced spraying of carrots in Canada (Judd *et al.* 1985), insecticides remain the primary management method for *P. rosae*. Because of the loss of available insecticides through deregistrations and pest resistance, the development of alternative control methods for management of *P. rosae* and other root-feeding Diptera is essential. This paper reports on the testing of an exclusion fence as a physical control for management of carrot rust fly.

Cultural and physical control methods for the management of *P. rosae* have previously been developed. Planting of carrots at strategic times of the year (Ellis and Hardman 1988), planting in low-risk areas along with proper crop rotations (Kettunen *et al.* 1988), or the use of resistant varieties (Ellis and Hardman 1988), have been used by organic growers to reduce damage. To date, physical control methods have been limited to the use of row covers which reduce damage by *P. rosae* and other vegetable pests such as the cabbage maggot, *Delia radicum* (L.) (Haselli and Konrad 1987; Ellis and Hardman 1988; Folster 1989; Antill *et al.* 1990; Davies *et al.* 1993). However, row covers are usually considered impractical for use in North America because of the high costs of material, labour, deployment and management.

Vernon and MacKenzie (1998) recently described the use of an exclusion fence for retarding the colonization of rutabagas by cabbage maggots. A 120cm high fence of window-screen mesh with a 22cm downward-sloping mesh overhang at the apex reduced the entry of *D. radicum* females and subsequent maggot damage in small plantings of rutabagas. It was suggested that exclusion fences could be used for control of *D. radicum* in other cruciferous crops like cabbage, broccoli, cauliflower and Brussels sprouts. Because crop rotation is a common practice in vegetable production, it would be desirable to use permanently-erected exclusion fences against major insect pests of crops planted in rotation with crucifers, such as carrots.

The use of exclusion fences for insect control relies on the assumption that no resident population exists and immigrating insects travel below the top of the exclusion fence. Oviposition within fenced plantings of a crop is prevented when low-flying females are excluded by the fence. Both *D. radicum* (Vernon 1979; Tuttle *et al.* 1988) and *P. rosae* (Judd *et al.* 1985) have been shown to fly near the top of the canopy within fields of their respective host plants. It has also been reported that *P. rosae* migrates in and out of carrot fields during the course of the growing season. Because of these tendencies for low-elevation flight and within-season migration, it is likely that movements of *P. rosae* into a crop would be impeded by exclusion fences and that the rate of oviposition within fenced plantings would be reduced.

In this study, we tested the efficacy of exclusion fences for management of *P. rosae* in field plots of carrots. In particular, we compared colonization by adult *P. rosae* and emergence of second-generation progeny between field plots that were fenced and unfenced. In addition, we compared several measures of carrot damage between fenced and unfenced plots.

## MATERIALS AND METHODS

*Fence design.* The exclusion fence consisted of 1mm mesh nylon window screen panels (210cm long by 120cm high) (Stollco Industries Ltd.) oriented vertically and supported by wooden fence posts (7.5cm by 10cm by 120cm high, Figure 1). Panels were connected together such that they surrounded the field plots. At the top of each panel, a wooden fence top (2cm high by 8cm wide by 210cm long) was placed on the top edge of the aluminum panel frame. Along the wooden fence top, a 60cm wide strip of 1mm mesh nylon window screen was attached such that 25cm of screen was exposed on either side of the fence and was angled downward at 45° on both sides (Figure 1). The mesh overhangs were secured by plywood triangles attached to the tops of the fence posts. The overhangs were intended to retard intercepted flies from moving up and over the fence. All fence components, including the mesh screens, were black in colour.

*Description of field site.* The study was conducted in 1993 in a 4 hectare commercial field located at Cloverdale, BC. The field had a highly organic muck soil, and a history of high populations of *P. rosae* along the western edge of the field. The western edge of the field was characterized by tall trees and stinging nettles (*Urtica dioica* L.) which are commonly associated with high populations of *P. rosae* (Wainhouse and Coaker 1981). On 20 April, four parallel beds of carrots cv. Six Pak were precision seeded in a north-south direction along the western edge of the field. Each bed had four rows of carrots with 45cm between the rows, and 1.8m between adjacent bed centres. The carrots were separated from the underbrush at the western edge of the field by a 10m strip of grass which was mowed every 2 weeks. The rest of the field was seeded with onions beginning about 10m to the east of the carrots. The plots were sprayed once on 15 May with linuron for weed control, and were hand-weeded thereafter.

*Experimental design.* Fences were erected between 30 April and 4 May; each was 8m by 8m, and enclosed 8m sections of the four beds of carrots. Control plots were identical in size and had the fence framework erected alone without the vertical mesh but including the mesh overhangs. Fenced and control plots were arranged in a randomized complete block design with four replicate blocks. Paired treatments within blocks were separated by a distance of 8m, and
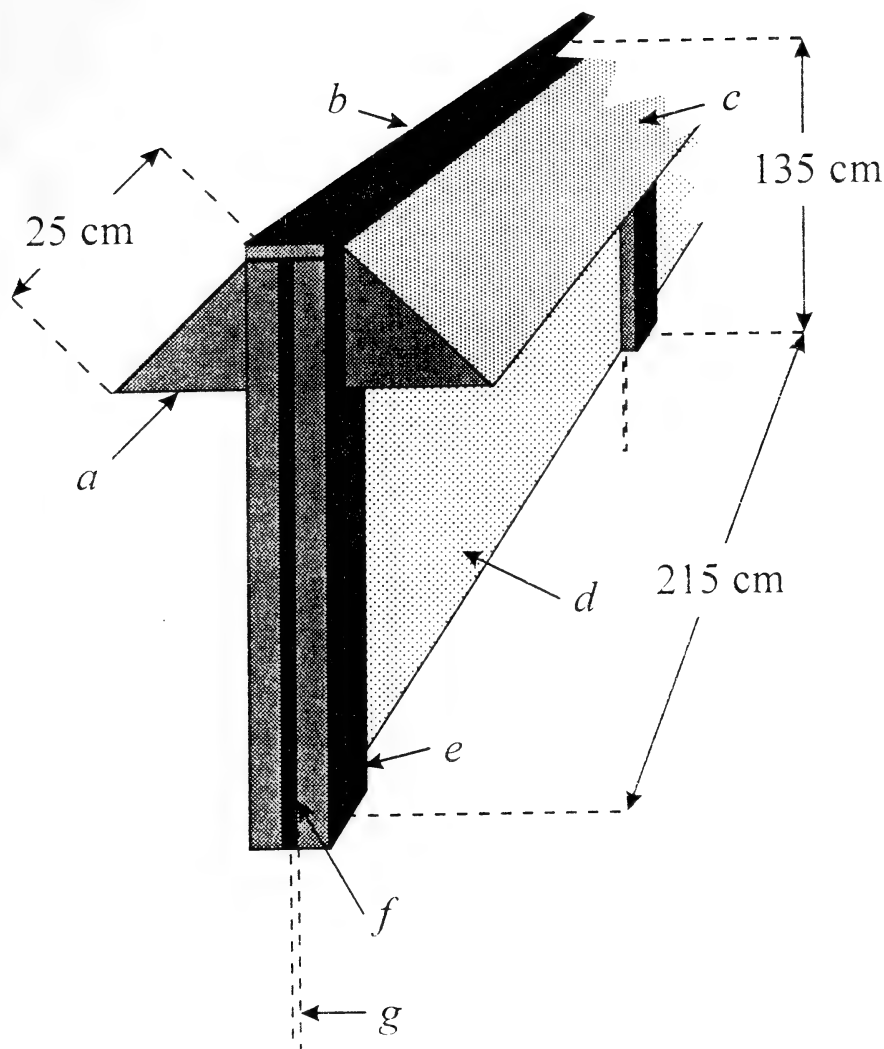
**Figure 1.** Design of exclusion fences with 25cm overhangs. Fence components include (a) overhang support wing, (b) wooden fence top, (c) mesh overhang, (d) mesh screen, (e) hollow wooden fencepost, (f) groove in post for screen, and (g) rebar to anchor post.

replicate blocks were separated by at least 10m. Fences were removed from all experimental and control plots on 16 September.

*P. rosae trapping.* Yellow sticky traps (11 by 14cm, Vernon *et al.* 1994) coated on both sides with Sticky Stuff (Olson Products, Medina, OH) were used to sample adult *P. rosae* within fenced and control plots. Single traps were placed on wooden stakes in the center of each fenced or control enclosure on 4 May. The tops of the traps were set initially at 20cm above the ground, and were raised in height during the season as the crop grew. The traps were oriented to face north and south and were located between the second and third beds of carrots. Traps were

replaced on 21 and 25 May, 1, 4, 7, 14, 17, 22, and 28 June, 5, 12, 20, and 27 July, 3, 10, 17, and 25 August, and 1, 10 and 16 September. The number of adult *P. rosae* on traps returned to the laboratory were counted and recorded as the number of *P. rosae* captured per enclosure per trapping period. Trap captures before 5 July were from the first (overwintered) *P. rosae* generation of 1993, and trap captures after 12 July were from the second generation of 1993.

Between 13 and 15 July, 6 wooden emergence pyramids (Giles 1987) were placed in each fenced and control enclosure to measure the emergence of the second generation of *P. rosae*. The emergence pyramids were boxes constructed of plywood in the shape of a pyramid, 100cm long and 30cm wide, and fit with a collecting jar at the apex. Pyramids were centered 2, 4 and 6m along each of the middle two beds of carrots. Each pyramid straddled the two middle rows of carrots in each bed. To facilitate the placement of the pyramids, carrots occupying about 30cm of row at the start and end of the pyramid were removed. The foliage of the remaining carrots under the pyramids was clipped to about 10cm, and the pyramids were sealed with soil along the base. *P. rosae* adults that emerged into plastic vials atop the pyramids were removed and counted on 17, 19, 21, 23, 25, 27, 29 and 30 July, and 1, 3, 4, 6, 8, 10, 12, and 17 August. Counts for the six pyramids within each enclosure were totalled for each sampling date and recorded as the number of *P. rosae* that emerged per enclosure per trapping period.

*Carrot damage assessment.* Carrots were harvested on three dates to compare levels of damage between fenced and control enclosures. On 13-14 July, the carrots removed to facilitate placement of emergence pyramids were retained as a damage sample. On 11 August, samples of carrots were taken 1, 3, 5, and 7m along the westernmost of the two central beds in each fenced and control enclosure. The samples consisted of 10 carrots taken from the middle row of the bed in areas not covered by emergence pyramids (for a total of 40 carrots per enclosure). On 20 September, samples of 25 carrots each were taken 2 and 4m along the middle row of the bed located farthest west in each enclosure.

Samples of carrots from all three dates were examined and classified as marketable or unmarketable. Marketable carrots had no lesions, or a single, inconspicuous lesion that would not be obvious to consumers. Unmarketable carrots had one or more conspicuous feeding holes present. The percentage of unmarketable carrots was calculated for each enclosure for each sample date.

For samples from 11 August and 20 September, carrots were divided into those that were marketable and unmarketable. Carrots from these two categories were weighed as groups. The yield (total weight of all carrots in each sample), mean weight per carrot (yield divided by the number of carrots in the sample) and percentage of the yield in the unmarketable category were calculated. For the sample from 20 September, the number of feeding sites on each carrot was counted and recorded as the number of lesions per carrot.

*Statistical analysis.* All trap capture data from yellow sticky traps were square-root transformed (i.e. sqrt $(X + 0.5)$) before analysis. Trap capture data from the first generation of *P. rosae* (21 May to 5 July) and the second generation (12 July to 16 September) were analysed separately. The number of *P. rosae* adults captured on sticky traps in particular trapping sessions throughout the season was compared between fenced and control enclosures using repeated-measures analysis of variance (ANOVA). The total number of *P. rosae* adults captured by emergence pyramids in each enclosure on particular collection dates was compared between fenced and control enclosures using repeated-measures ANOVA for the entire season's data, and using t-tests for individual sample dates. Proportional measures of carrot damage were arcsine transformed before analysis (i.e. arcsin(sqrt $(X)$)). The percentage of unmarketable carrots, % yield unmarketable, mean weight per carrot, and number of lesions per carrot were compared between fenced and control enclosures by t-tests separately for data from different sample dates. Means and standard errors of all transformed variables were back-transformed for reporting

purposes. All statistical analyses were conducted using Systat for Windows, Version 5.0 (Wilkinson *et al.* 1992).

# RESULTS

*P. rosae trapping.* More first generation *P. rosae* were captured on sticky traps in control enclosures than in fenced enclosures, but this difference was not statistically significantly (Table 1). Similarily, more second generation *P. rosae* adults were captured in control enclosures than in fenced enclosures, but this was difference was not statistically significant (Table 1). The mean number of *P. rosae* adults captured in emergence pyramids was significantly higher in control enclosures than in fenced enclosures when data for the entire season was analysed (Table 1). When data were analysed for individual sample dates, the mean number of *P. rosae* captured in emergence pyramids was significantly higher in control enclosures than in fenced enclosures for 8 of the 16 sample dates (Figure 2).

## Table 1

Trap captures on yellow sticky traps and captures from emergence pyramids of *Psila rosae* per trapping period in fenced and unfenced enclosures (Mean ±SE). Means in rows followed by the same letter are not significantly different by repeated-measures ANOVA ($p>0.05$).

| Trapping method | *P. rosae* generation | Treatment | | *F* | df | *p* |
|---|---|---|---|---|---|---|
| | | Control | Fenced | | | |
| Yellow sticky traps | First | 0.5 ± 0.2 a | 0.1 ± 0.1 a | 2.97 | 1,6 | 0.14 |
| Yellow sticky traps | Second | 1.4 ± 0.3 a | 0.9 ± 0.2 a | 1.40 | 1,6 | 0.28 |
| Emergence pyramids | Second | 5.5 ± 0.5 a | 1.5 ± 0.2 b | 20.29 | 1,6 | 0.004 |
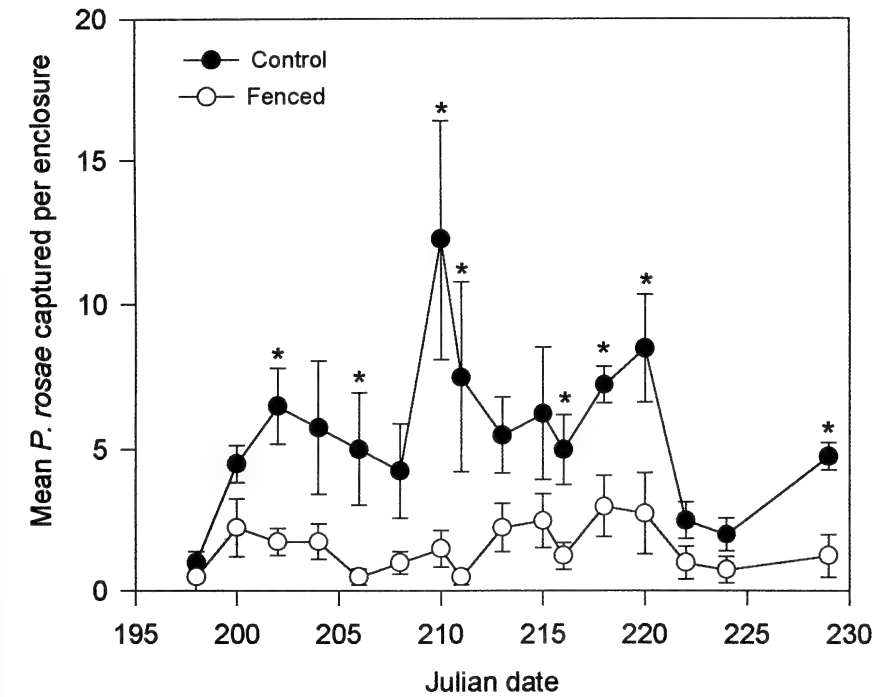


**Figure 2.** Mean number of *P. rosae* adults captured in emergence pyramids within fenced and unfenced enclosures on 16 sample dates in 1993. Dates where significant differences in captures between fenced and control enclosures were detected by t-tests (at $p<0.05$) are marked by an asterix. Error bars indicate standard errors of means.

*Carrot damage assessment.*   The percentage of unmarketable carrots was significantly higher in control enclosures than in fenced enclosures for damage samples taken on 11 August and 20 September (Table 2).  The percentage of yield unmarketable was also significantly higher in control enclosures for the samples of 11 August and 20 September (Table 2).  However, the mean weight per carrot was not significantly different between fenced and control enclosures for either of these sample dates (Table 2).  Finally, the number of lesions per carrot was significantly higher for control enclosures than for fenced enclosures for the sample of 20 September (Table 2).

## Table 2

Damage to carrots caused by *Psila rosae* in fenced and unfenced enclosures (Mean ±SE).  Means in rows followed by the same letter are not significantly different by t-tests ($p$=0.05).

| Sample date | Variable | Treatment | | $t$ | $p$ |
| --- | --- | --- | --- | --- | --- |
| | | Control | Fenced | | |
| 13 July 93 | % Unmarketable | 3.2 ± 1.5 a | 0.5 ± 0.3 a | 2.2 | 0.07 |
| 11 August 93 | % Unmarketable | 8.1 ± 3.3 a | 0.6 ± 0.6 b | 3.3 | 0.02 |
| | % of yield unmarketable | 10.9 ± 6.8 a | 0.6 ± 0.6 b | 2.5 | 0.05 |
| | Weight per carrot (g) | 71.9 ± 3.9 a | 94.3 ± 11.1 a | 1.9 | 0.10 |
| 20 Sept. 93 | % Unmarketable | 87.0 ± 5.8 a | 38.7 ± 12.9 b | 3.3 | 0.02 |
| | % of yield unmarketable | 91.9 ± 4.8 a | 47.7 ± 14.2 b | 3.1 | 0.02 |
| | Weight per carrot (g) | 134.8 ± 13.2 a | 149.6 ± 19.6 a | 0.6 | 0.55 |
| | Lesions per carrot | 4.8 ± 0.8 a | 0.7 ± 0.3 b | 4.6 | 0.004 |

## DISCUSSION

Although no statistical differences could be detected between mean captures of adult *P. rosae* on sticky traps in fenced *vs.* control enclosures, the emergence of second generation progeny was significantly lower in fenced enclosures than in control enclosures.  This suggests that *P. rosae* females entering the field were prevented from colonizing the plots by the fences, resulting in decreased oviposition within fenced enclosures.  Carrot damage was also substantially reduced within fenced enclosures compared to control enclosures.  These data indicate that exclusion fences show considerable promise as a management method for carrot rust fly.

Captures of *P. rosae* on sticky traps in the first generation of 1993 were very low.  However, the amount of damage resulting from colonization of carrots by even this moderately-low population of *P. rosae* was substantial in control plots (3.2%).  Currently no economic injury level for carrots in BC has been defined, but damage levels greater than 5% usually draw attention during the grading process (R. Vernon, personal observation). The level of protection of carrots provided by exclusion fences has the potential to substantially reduce damage caused by this pest.  The use of exclusion fences in combination with cultural controls might be an effective management strategy for *P. rosae*.  For example, careful timing of carrot planting and harvest dates to avoid periods with the maximum damage potential could be combined with the use of exclusion fences.

Although carrot damage in fenced enclosures was always lower than in control enclosures, the level of damage recorded in fenced enclosures on the final sampling date was above what is tolerable for commercial carrot production.  The damage recorded in the final sampling date was caused by the progeny of second generation *P. rosae* that emerged within the plots.  If these carrots had been harvested before the flight period of second generation *P. rosae* occurred, much of this damage would have been prevented.

Exclusion fences have been shown to impede the colonization of rutabagas by the cabbage maggot, *D. radicum* (Vernon and MacKenzie 1998). The fences will likely also protect plantings of other brassica crops from damage by *D. radicum*, and could possibly prevent damage to plantings of onions by the onion maggot, *Delia antiqua* (Meigen) (R.S. Vernon, unpublished data). If exclusion fences are effective against a variety of pest species that attack different vegetable crops, it may be practical to erect permanent fences around vegetable fields where carrots, onions and brassicas are planted in rotation. The effectiveness of exclusion fences for management of carrot rust fly and other vegetable pests in large commercial fields remains to be tested.

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# Is it possible to use mass-reared or field-collected diapaused codling moth larvae, *Cydia pomonella* (Lepidoptera: Tortricidae), to predict spring biofix?

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## ABSTRACT

Codling moths, *Cydia pomonella* (L.), from a mass-reared colony induced into diapause and from locally collected overwintering populations were placed in the field inside mesh cages in the fall of 1997 to determine whether they would synchronize their spring emergence with the wild population and thus could be used as a tool to set biofix. Our results show that the laboratory-reared moths emerged at approximately the same time regardless of the location where they spent the winter. Locally collected (and caged) wild material always emerged later than the remaining wild population and thus was no better at predicting biofix than were laboratory-reared insects.

**Key words:** *Cydia pomonella*, diapause, biofix, emergence

## INTRODUCTION

The codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), is the key pest of apples and pears in the Pacific Northwest (Madsen and Procter 1982). It is a multivoltine species that possesses facultative diapause (Riedl 1983; Brown 1991). In the Okanagan and Similkameen Valleys of British Columbia, codling moth typically completes two generations per year (Madsen and Vakenti 1973), and in the Yakima Valley of Washington, USA, it completes two generations per year with a possible small third generation occurring in some seasons (Newcomer and Whitcomb 1924). Wild codling moths spend the winter as mature 5th-instar larvae in diapause, defined by Dickson (1949) as a physiological stage of arrested development that enables an organism to survive unfavorable conditions. Silken hibernacula are spun under loose bark scales, in litter at the base of trees, on tree props or fruit bins in the orchard or on farm buildings near cull piles (Beers *et al.* 1993). Overwintering larvae break diapause and pupate inside their cocoons in early spring about the time when the first apple blossoms show pink color (Beers *et al.*

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1993). In southern BC, peak flight activity of overwintered adults occurs in early May, and in late July-early August for the summer generation (Madsen and Procter 1982).

Biofix is a biological fix point used to synchronize phenology (or day-degree) models with insect development (Beers *et al.* 1993). Phenology models for *C. pomonella* were developed by Riedl *et al.* (1976), and are widely used to predict codling moth egg hatch and to time more precisely the application of pesticide cover sprays. To determine biofix for codling moth, growers typically place pheromone-baited traps in the orchard before apple flower-bud development to capture the emerging overwintered adults. The date male moths first begin to be consistently captured in pheromone traps (e.g., one or more moths captured on successive days) is used to set biofix. Codling moth pheromone-baited traps have been shown to be only about 10% efficient at capturing feral moths when deployed at the standard trap density of one per ha (Anonymous 1997). When feral populations are small or when trap densities are lower than recommended, it might be difficult to determine when to set biofix, which in turn will lower the predictive accuracy of the codling moth phenology model.

We have developed the technology to induce laboratory-reared *C. pomonella* into diapause in the open tray diet system used for mass-rearing these insects in BC, Canada (Bloem *et al.* 1997, 1999). Mass-rearing under conditions of diapause induction allows for the collection of large numbers of overwintering larvae into corrugated cardboard rolls. Some of the benefits of producing insects in this manner have been discussed elsewhere (Bloem *et al.* 1998, 1999). Here we examine the possible use of laboratory-reared larvae in diapause as a tool to help set biofix in the field. Specifically, we asked the questions: 1) Do codling moths induced into diapause in the laboratory emerge similarly to wild *C. pomonella* when placed in the field and exposed to the same winter field conditions, and 2) can field emergence of the laboratory-reared insects be used to accurately set biofix?

## MATERIALS AND METHODS

### Experiment 1: Effect of Induction Conditions on Spring Emergence

*Sample Preparation and Collection.* On 18 August 1997, laboratory-reared codling moth larvae were induced into diapause under mass-rearing conditions at the SIR rearing facility in Osoyoos, BC, by altering the photoperiod and temperature during rearing as outlined in Bloem *et al.* (1997). However, to improve the efficiency of induction into diapause the temperature during scotophase was lowered to 21°C. Mature diapaused larvae were collected into C-flute corrugated cardboard rolls (15.25 cm diam. x 2.50 cm) when exiting the diet. The infested rolls were stored at 15°C, 0L:24D and 60% RH inside black polyethylene bags until needed.

Samples of diapaused summer generation wild *C. pomonella* were collected from infested apple orchards in Kelowna and Creston, BC, by placing corrugated cardboard bands around the trunks of apple trees in mid-August, and removing the bands infested with overwintering larvae from the trees in early November 1997. Bands were stored as indicated above for laboratory-reared insects. Diapaused codling moth larvae from Osoyoos, BC, were collected from infested apples removed from local orchards in mid-September 1997, by SIR Program staff. Apples were placed into 12 large plastic bins (125 x 50 x 40 cm) that had been lined with corrugated cardboard strips. The bins were covered with thin muslin cloth and placed under shelter in an Osoyoos orchard for 6 weeks to allow the larvae to exit the fruit. At that time, bins were uncovered, apples were discarded, and the cardboard strips removed and stored in bags as described above.

On 15 November 1997, the cardboard rolls and bands containing diapaused laboratory-reared and wild codling moth larvae were prepared for field placement inside a walk-in cold room (0-2°C). Material from each of the four cohorts (laboratory, Kelowna, Creston

and Osoyoos) was divided into three equal groups, and each group was placed into an individual cylindrical fiberglass mesh and wire cage (23 cm diam. x 60 cm). Cages with laboratory-reared material contained no fewer than 100 larvae in diapause. The number of larvae in each wild sample varied, but was never less than 25 larvae per cage.

*Field Placement and Cage Monitoring.* On 20 November 1997, the cages containing wild-collected and laboratory-reared diapaused larvae were transported inside coolers to an apple orchard in each of three locations - Kelowna, Creston and Osoyoos, BC. The orchard at each location was an established traditional planting of 'Red Delicious' trees (avg. tree height ca. 4 m, row spacing 5.5 x 3.7 m). Because codling trap captures throughout the SIR treatment area (i.e., in Osoyoos and Creston) were generally low in 1997, the orchards were chosen for having known codling moth infestations, as well as for general similarities in orchard structure. Four cages, one from each cohort, were hung in each orchard at the three locations in apple trees at a height of 1.5-2.0 m above ground and within 10 m of one another. The cages remained in the orchards until the following spring. In mid-April 1998, pheromone-baited codling moth traps were hung (one trap/ha and five traps/orchard; traps were hung in the upper 1/3 of the tree canopy) in the same orchards where the cages were located, but no closer than 25 m to the cages, to capture wild codling moth males emerging from diapause. Adult moth emergence inside each cage, and trap captures at each location were checked daily beginning on 15 April 1998. Biofix at each location, both inside the cages and in the orchard, was set when one or more male moths were captured on successive days.

**Experiment 2: Synchroneity of Emergence of Laboratory-Reared and Wild Moths**

*Sample Preparation.* Laboratory codling moth larvae were induced into diapause, allowed to enter corrugated cardboard rolls and stored until needed as described above. On 30 November 1997, the cardboard rolls with diapaused larvae were prepared for field placement inside a cold room (0-2°C). Material was divided into six groups and placed into cylindrical fiberglass mesh and wire cages as described for Experiment 1. Each cage contained no fewer than 100 larvae and was kept in the cold room until needed.

*Field Placement and Cage Monitoring.* In early December 1997, the cages containing laboratory-reared diapaused larvae were transported inside coolers to pre-selected orchards located roughly along a north-south gradient from Creston, BC, Canada, to the north and Medford, Oregon, USA, to the south. Although Creston is actually 400 km east of Osoyoos in the Kootenay Mountains of BC, it was chosen as our "northern-most" site because of its cooler temperatures and historically late codling moth emergence in the spring compared to other locations at the same latitude. Locations in between the north and south endpoints were: Osoyoos, BC, Canada, Oroville, Washington, Wenatchee, WA, and Hood River, Oregon, USA. One cage with diapaused material was hung in an apple orchard at each of these locations where it remained until the following spring. In late March 1998, pheromone-baited codling moth traps were hung and used as indicated above. Adult moth emergence in each cage and trap captures at each location were checked daily beginning on 30 March 1998. Biofix for caged material and wild populations was established as previously indicated.

## RESULTS AND DISCUSSION

The biofix dates for laboratory-reared and field-collected diapaused codling moth larvae caged at different locations in southern British Columbia, and the biofix dates for the wild populations captured in pheromone-baited traps at each location, are presented in Table 1. As expected, biofix for orchard populations of wild moths occurred first in Osoyoos, followed by Kelowna, and then Creston. At all locations, biofix for the caged laboratory-reared material occurred before biofix was set for the wild population using trap

**Table 1**

Biofix dates for caged laboratory-reared and field-collected diapaused *Cydia pomonella* larvae held at different locations in southern British Columbia, and biofix dates using adult male moth captures in pheromone-baited traps at these locations in the spring of 1998.

| | Biofix date (d/mo.) | | |
|---|---|---|---|
| Source of material | Osoyoos | Kelowna | Creston |
| Pheromone-baited trap | 29/4 | 03/5 | 21/5 |
| | | | |
| Caged diapausing larvae | | | |
|     Laboratory-reared | 27/4 | 30/4 | 04/5 |
| | | | |
|     Wild collected | | | |
|         Osoyoos | 04/5 | 10/5 | 06/5 |
|         Kelowna | 06/5 | 09/5 | 12/5 |
|         Creston | 01/6 | - [a] | 09/6 |

[a] No adults emerged from the Creston sample that was overwintered in Kelowna. The source of larval mortality could not be determined.

catch data. The number of days prior to orchard biofix that caged laboratory-reared material consistently began emerging was +2, +3, and +17 days for the Osoyoos, Kelowna, and Creston locations, respectively. Similarly, at all locations, the caged laboratory-reared moths began emerging before (+2 to +36 days) any of the caged field-collected material. Although these data are not presented, at each location once the laboratory-reared material began to emerge the pattern of emergence followed a typical bell-shaped curve as described by Bloem *et al.* (1997). Unlike the results for laboratory-reared codling moth larvae, caged field-collected larvae that overwintered at the same location where they were collected always emerged after the first trap captures occurred at that site. For example, biofix for the wild population in Osoyoos occurred on 29 April 1998, while biofix for the caged field-collected larvae from Osoyoos occurred on 4 May 1998 at the Osoyoos site.

Results from the experiment comparing biofix dates for diapaused laboratory-reared *C. pomonella* maintained in the field at different locations along a north-south gradient (from British Columbia, Canada, to Oregon, USA) with biofix dates for wild populations at the same locations are shown in Table 2. As in the first experiment, wild moth trap captures occurred earlier in the year at more southerly locations. Biofix occurred on 22 April 1998, in Medford, OR, USA, and on 21 May 1998, in Creston, BC, Canada. Unfortunately, biofix for the caged laboratory-reared material occurred between 27 April and 6 May 1998 at all sites, with no clear south-to-north trend.

Our results suggest that SIR colony codling moths induced into diapause in the laboratory and emerged under field conditions cannot be used to accurately set biofix at sites south of the SIR rearing facility. At these sites, biofix determined by emergence of caged laboratory-reared material occurred increasingly later than biofix for field populations determined using pheromone traps. However, as the experiment moved north of Osoyoos laboratory-reared moths emerged increasingly earlier than wild moths. As such, diapaused codling moths produced at the SIR facility would appear to have potential for use in fruit growing areas of southern BC to predict biofix, better time the initiation of spring sterile moth releases by the SIR Program and/or to establish times to set-out pheromone traps. Additional research would be needed to determine the consistency with which emergence of colony material precedes wild emergence at each location.

**Table 2**

Spring 1998 biofix dates for laboratory-reared diapaused *Cydia pomonella* larvae overwintered in the field at different locations along a north-south gradient, and biofix dates for orchard populations of *C. pomonella* captured in pheromone-baited traps at these same locations.

| Location | Caged lab-reared material[a] | Biofix date (d/mo.) Wild male moth trap captures | Time between emergence of lab-material and 1st trap captures (days) |
|---|---|---|---|
| N Creston, BC | 04/5 | 21/5 | +17 |
| Osoyoos, BC | 27/4 | 29/4 | +2 |
| Oroville, WA | 04/5 | 02/5 | -2 |
| Wenatchee, WA | 02/5 | 27/4 | -5 |
| Hood River, OR | 06/5 | 27/4 | -9 |
| S Medford, OR | 06/5 | 22/4 | -14 |

[a] Laboratory material was reared and induced into diapause at the SIR Program codling moth mass-rearing facility in Osoyoos, BC.

It is interesting to note that field emergence of the caged laboratory-reared codling moths most closely approximated the timing of emergence of the Osoyoos wild population. This laboratory colony has been in continuous culture since 1988, initially at the Summerland Pacific Agriculture and Agri-Food Research Centre and then at the SIR mass-rearing facility in Osoyoos. The majority of the wild material used to "found" the colony came from orchards in the south Okanagan Valley and subsequent attempts to introduce wild genetic material into the colony have also come largely from orchards in and around Osoyoos.

Locally collected and caged wild material was no better at predicting biofix than were laboratory-reared insects. Wild diapaused larvae collected, caged and maintained at the same location emerged 1-2 weeks after moths were captured in biofix traps placed in that orchard (Table 1). Why locally collected, wild, diapaused material emerged consistently later than the non-collected population is not known. One possible explanation is that our field-collected samples were too small, and thus showed narrower emergence extremes relative to the wild population captured in the pheromone traps. Another possibility may be related to the fact that field samples were only collected in the fall (mid-August) and thus were taken from summer (or second) generation populations exclusively. According to Riedl (1983), a certain percentage of codling moth populations are composed of genetically univoltine larvae that enter diapause after one generation even under favorable long-day conditions. It is possible that larvae that enter diapause at the end of the spring (or first) generation are the first ones to emerge as adults the following spring, with second generation larvae (entering diapause in the summer and fall) emerging somewhat later. Cisneros (1971) and Phillips and Barnes (1975) also suggest that the first individuals to enter diapause are the first to emerge the following year; however, according to Riedl (1983) the evidence for this is still unclear. A third explanation for our results might be that there was a temperature difference between where the cages were placed and the location of overwintering sites chosen by feral populations. Larvae that spun hibernacula under tree bark and in other typical overwintering sites near the ground could have

accumulated heat units faster than did the larvae inside the cardboard rolls in our cages hung in apple trees and thus emerged sooner. Although, this argument would not explain the emergence pattern observed for the laboratory-reared material (no north-south variation in emergence date and Osoyoos laboratory material emerged similarly to Osoyoos orchard population).

Reactivation of larval development after diapause must occur at the right time to synchronize adult emergence in the spring with fruit development (Riedl 1983). The role of temperature in the regulation of physiological development is the basis upon which predictive day-degree models are constructed. Data collected by the SIR Program between 1993 and 1999 showed that site-specific biofix dates in the Okanagan and Creston Valleys, BC, varied by more than 4 weeks (e.g., 9 May in 1993 and 14 June in 1999 in Creston). However, in our experiments, artificially moving diapaused codling moths to different locations, with different winter-spring conditions, did not appear to have a notable impact on their emergence date. Wild material collected and caged at Osoyoos, BC, emerged on 4 May 1998 in Osoyoos and on 6 May 1998 in Creston, BC, compared with orchard biofix dates of 29 April 1998 and 21 May 1998 for Osoyoos and Creston, respectively (Table 1). Likewise, caged laboratory-reared insects placed at Medford, OR (the southern most location in our experiment) emerged on 6 May 1998 and 2 days earlier at the northern most location in Creston, BC, on 4 May 1998 (Table 2). In contrast, orchard biofix at these locations occurred on 22 April and 21 May 1998, respectively.

Although the primary factors regulating diapause induction are short-days and cool temperatures (Riedl 1983), Garlick (1938, 1948) as discussed in Putman (1963) suggested a partial genetic basis to voltinism in the codling moth. Brown *et al.* (1979) also proposed a genetic-nutritional mechanism for diapause induction in the first generation when the primary overwintering cues are not present. In our experiments, the fact that the geographical location where diapause induction occurred played a more important role in determining when the insects emerged from diapause than did the conditions under which they spent the winter and spring (this held for both for laboratory-reared and field-collected insects) suggests a possible genetic component to diapause termination. Codling moth larvae from a localized population may be genetically predisposed to emerge within a limited range of dates that are selected based on historical weather patterns for the area. However, additional work is still needed to fully understand the factors that regulate termination of diapause in the field.

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